
# Evaluation of Hurricane Forecast Skills of NCEP GFS Retrospective Experiments for the FY2016 Implementation

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**Acknowledgments** : All NCEP EMC Global Climate and Weather Modeling Branch members are acknowledged for their contributions to the development of the Global Forecast Systems.

# Outline

1. **GFS Forecast Skill of Hurricane Track and Intensity in the Past 15 Years**

2. **Review of 2015 Performance**

3. **Upcoming GFS Upgrade in May 2016**

4. **Evaluation of GFS Retrospective Experiments: 2012-2015**

# Change History of GFS Configurations

| Mon/Year | Levels | Truncations | Z-cor/dyncore | Major components upgrade |
|---|---|---|---|---|
| Aug 1980 | 12 | R30 (375km) | Sigma Eulerian | first global spectral model, rhomboidal |
| Oct 1983 | 12 | R40 (300km) | Sigma Eulerian | |
| Apr 1985 | 18 | R40 (300km) | Sigma Eulerian | GFDL Physics |
| Aug 1987 | 18 | T80 (150km) | Sigma Eulerian | First triangular truncation; diurnal cycle |
| Mar 1991 | 18 | T126 (105km) | Sigma Eulerian | |
| Aug 1993 | 28 | T126 (105km) | Sigma Eulerian | Arakawa-Schubert convection |
| Jun 1998 | 42 | T170 (80km) | Sigma Eulerian | Prognostic ozone; SW from GFDL to NASA |
| Oct 1998 | 28 | T170 (80km) | Sigma Eulerian | the restoration |
| Jan 2000 | 42 | T170 (80km) | Sigma Eulerian | first on IBM |
| Oct 2002 | 64 | T254 (55km) | Sigma Eulerian | RRTM LW; |
| May 2005 | 64 | T382 (35km) | Sigma Eulerian | 2L OSU to 4L NOAH LSM; high-res to 180hr |
| May 2007 | 64 | T382 (35km) | Hybrid Eulerian | SSI to GSI |
| Jul 2010 | 64 | T574 (23km) | Hybrid Eulerian | RRTM SW; New shallow cnvtion; TVD tracer |
| Jan 2015 | 64 | T1534 (13km) | Hybrid Semi-Lag | SLG; Hybrid EDMF; McICA etc |

Vertical layers double every ~11 yrs; change of horizontal resolution is rapid (~30 times in 35 years); sigma-Eulerian used for 27 yrs!

Source http://www.emc.ncep.noaa.gov/gmb/STATS/html/model_changes.html

# Major GFS Changes Since 2000

- **2/2000**: **Resolution change: T126L28 → T170L42 (100 km → 70 km)**
  - **7/2000 --hurricane relocation**

- **5/2001**: **Major physics upgrade (prognostic cloud water, cumulus momentum transport)**
  - –Improved QC for AMSU radiances

- **11/2002**: **Resolution change: T170L42 → T254L64 (70 km → 55 km)**
  - 2003: NOAA-17 radiances, NOAA-16 AMSU restored, Quikscat 0.5 degree data
  - 2004: RRTM longwave and trace gases; **mountain blocking added**

- **5/2005**: **Resolution change: T254L64 → T382L64 ( 55 km → 38 km )**
  - **–2-L OSU LSM → 4-L NOHA LSM**

- **8/2006: NRL ozone physics**
  - –Upgrade snow analysis

- **5/2007: SSI (Spectral Statistical Interpolation) → GSI ( Gridpoint Statistical Interpolation).**
  - **–Vertical coordinate changed from sigma to hybrid sigma-pressure**
  - –New observations (COSMIC, full resolution AIRS, METOP HIRS, AMSU-A and MHS)

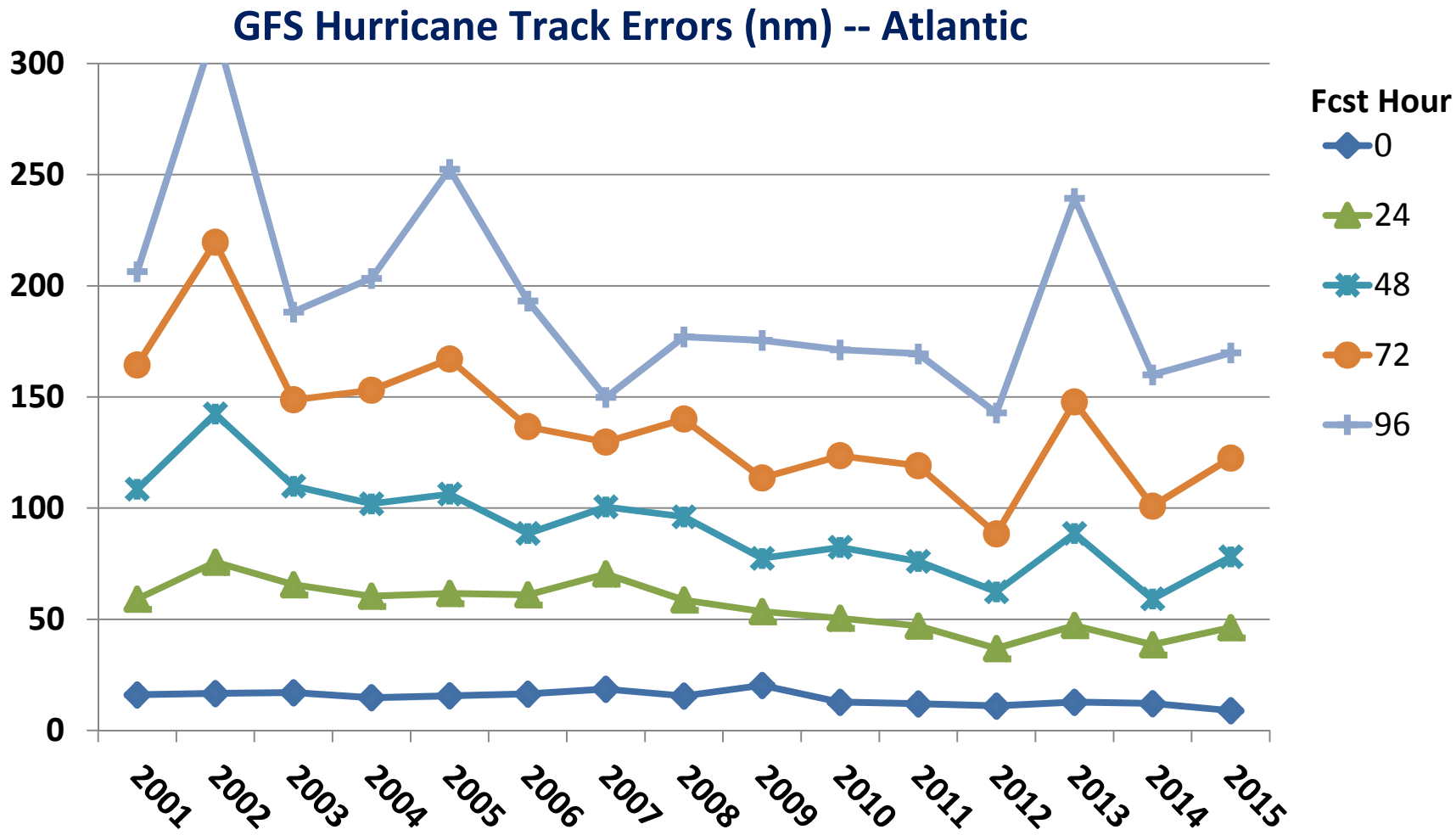
# Major GFS Changes (cont'd)

- **2/2009**: **Flow-dependent weighting of background error variances; Variational Quality Control;**
  METOP IASI observations added; Updated Community Radiative Transfer Model coefficients

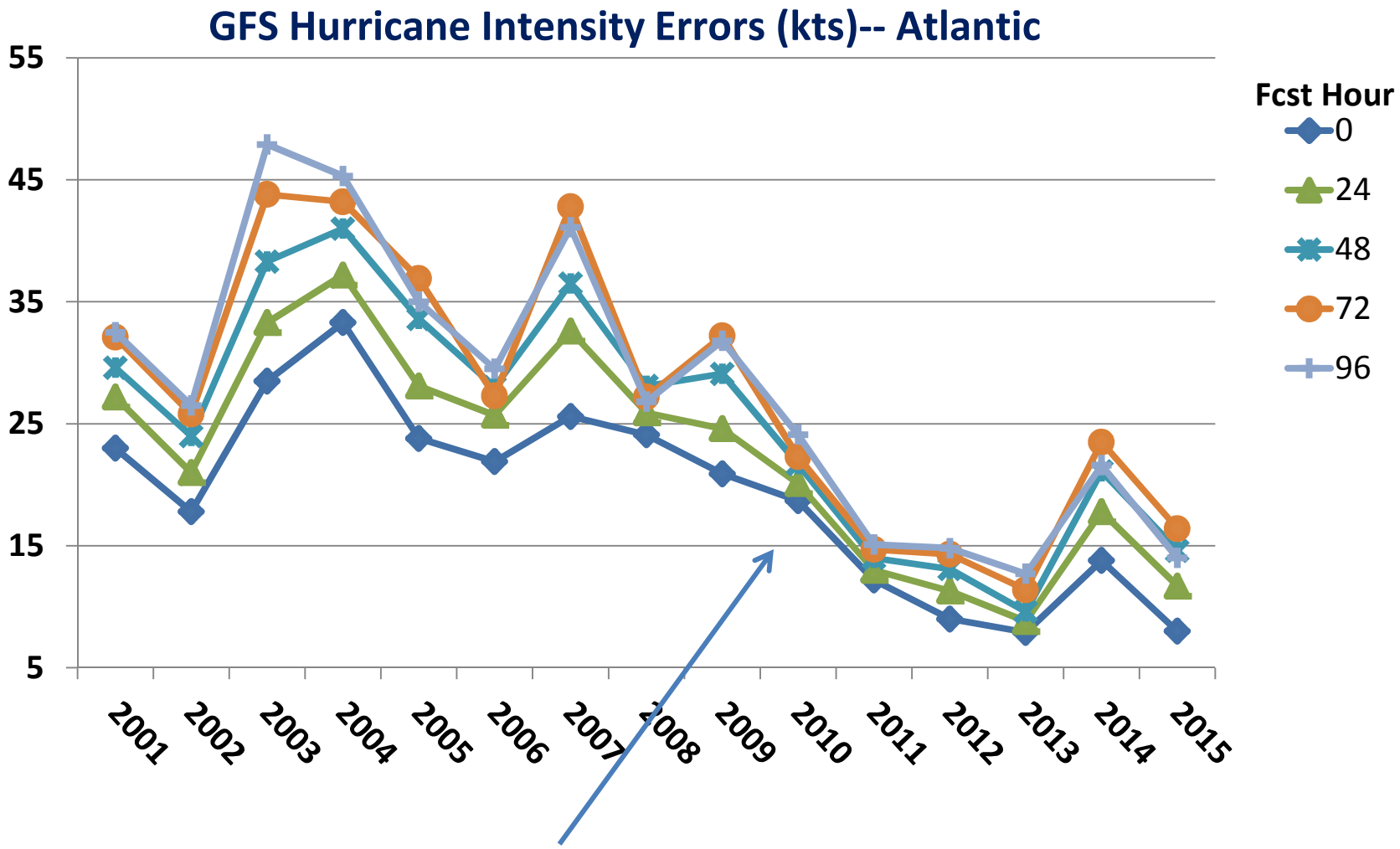
- **7/2010**: **Resolution Change: T382L64 → T574L64 ( 38 km → 23 km )**
  - **Major radiation package upgrade (RRTM2 , aerosol, surface albedo etc)**
  - **New mass flux shallow convection scheme; revised deep convection and PBL scheme**
  - **Positive-definite tracer transport scheme to remove negative water vapor**

- **5/22/2012: GSI Hybrid EnKF-3DVAR** : lower resolution (T254) Ensemble Kalman Filter.

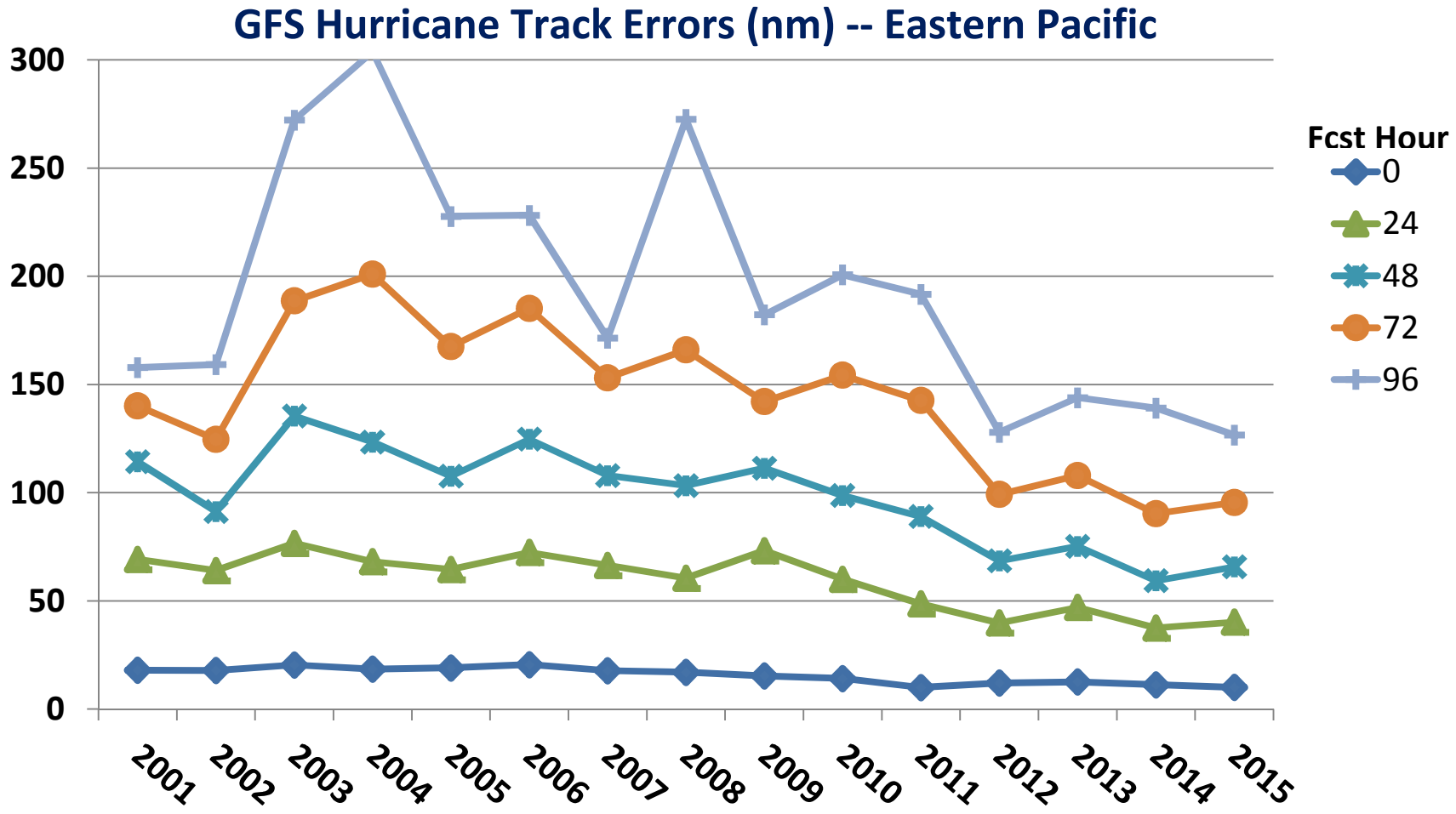
- **1/2015: Upgrade to T1534 Semi-Lagrangian (~13km)**
  - Use high resolution daily RGT SST and daily sea ice analysis; Use McICA radiation approximation; Reduced drag coefficient at high wind speeds; Hybrid EDMF PBL scheme and TKE dissipative heating; Divergence damping in the stratosphere to reduce noise; Stationary convective gravity wave drag; New blended snow analysis; Changes to treatment of lake ice to remove unfrozen lake in winter; Replace Bucket soil moisture climatology with CFS/GLDAS
  - **GSI Changes:** increase horizontal resolution of ensemble from T254 to T574; move to enhanced radiance bias correction scheme; assimilate new radiances: F17 an F18 SSMIS, MetOp-B IASI; assimilate NESDIS GOES hourly AMVs.



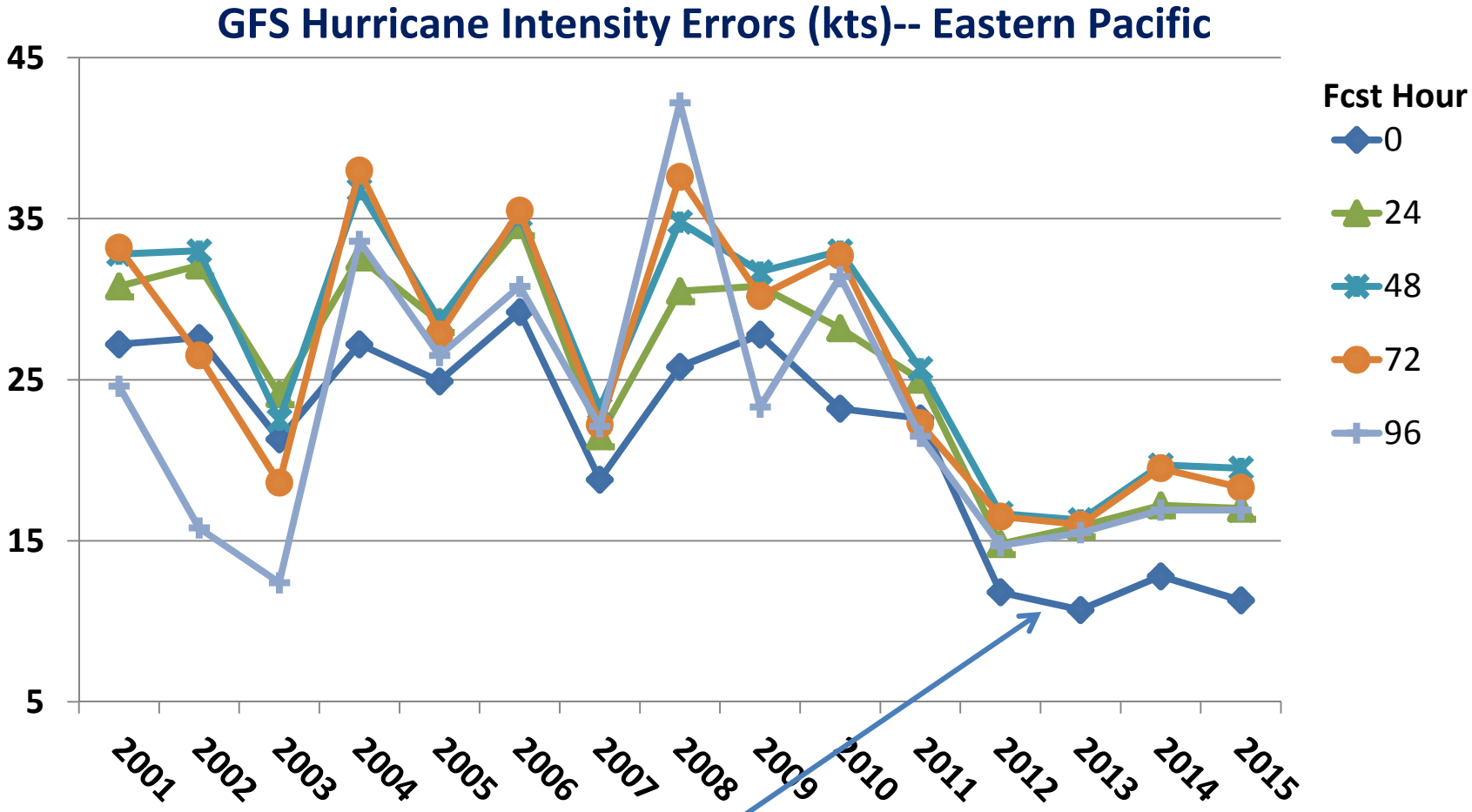

- **Track for all forecast leading time has been improved in the past 15 years; 72-hr track error reduced from ~150nm to ~100nm**



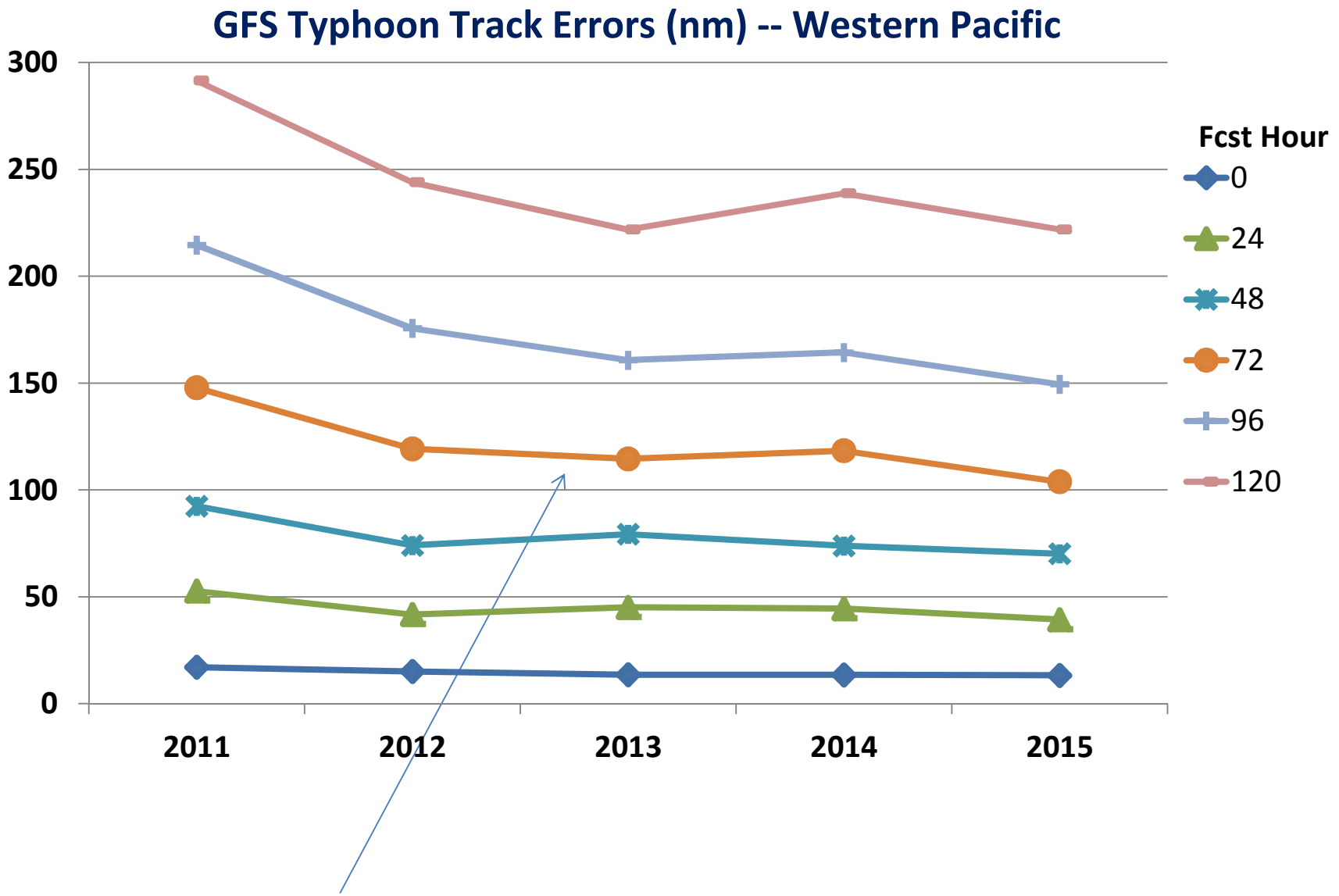

- **Intensity improved in 2010 and 2011 due to GFS resolution increase from 35km to 23km and major physics upgrade;**
- **in 2012 and 2013 due to ENKF-3DVAR GSI Implementation in May 2012;**
- **in 2015 due to T1534 SLG GFS (~13km) implementation.**




- **Significant track error reduction in the past 15 years.**
- **72-hr track reduced from 200 nm in 2004 to 100 nm in 2015 .**




- **Large reduction after 2010 T574 GFS Implementation**
- **3D En-Var DA (May 2012) reduced initialization error (?)**




**72-hr forecast error reduced from 150 to 100 nm in 5 years.**

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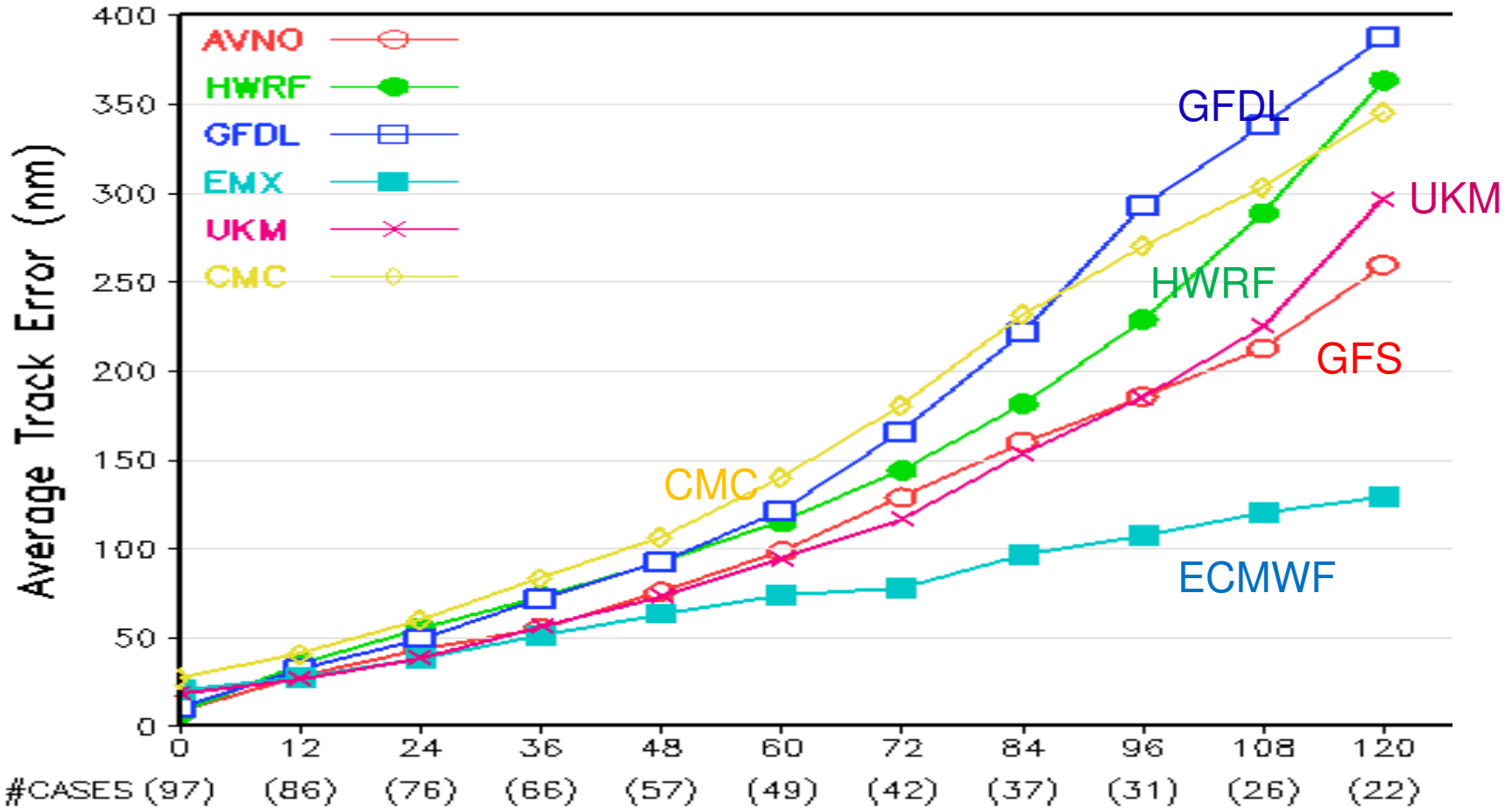
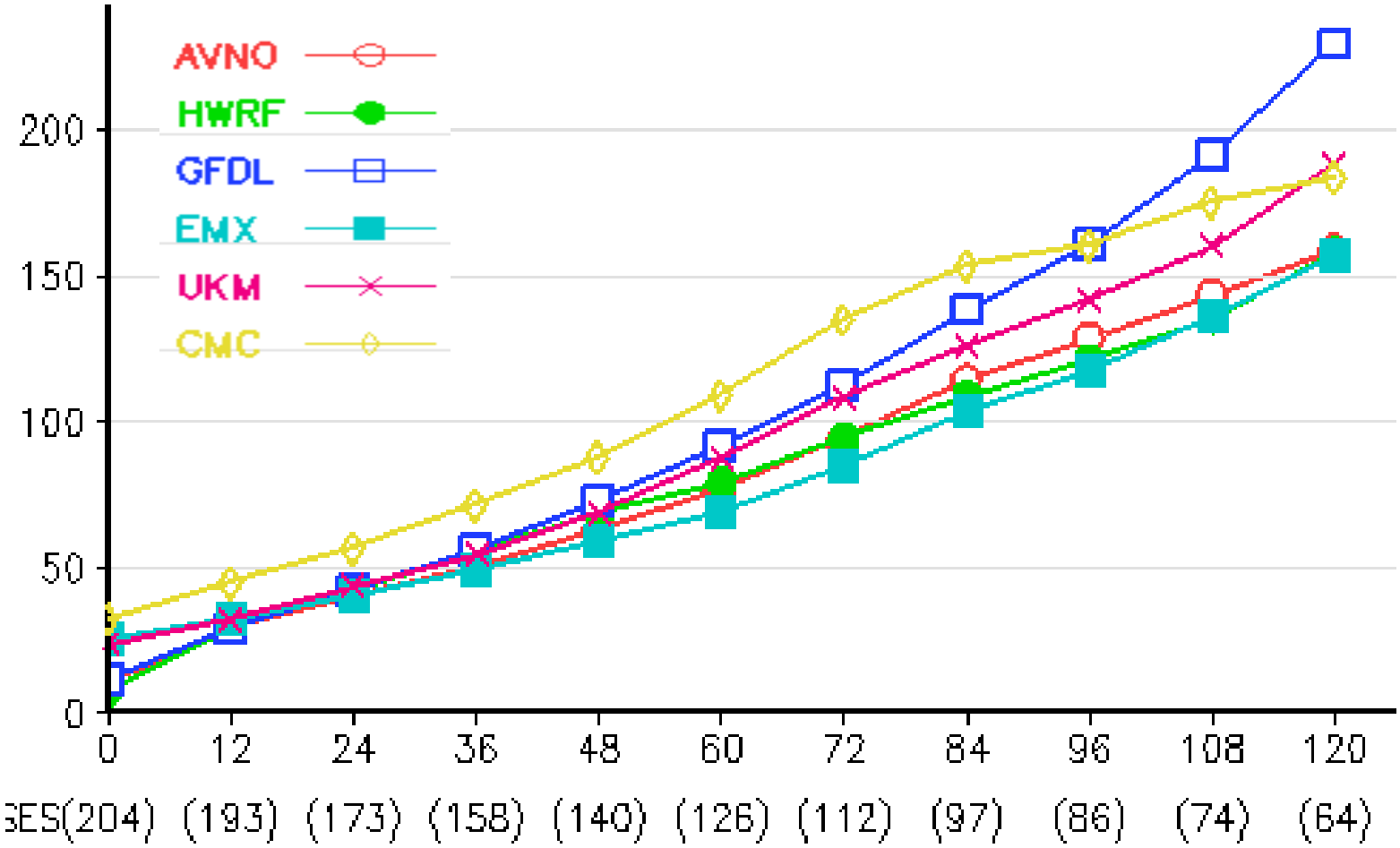
4. Evaluation of GFS Retrospective Experiments: 2012-2015

# 2015 Atlantic – Track Errors (00Z and 12Z Cycles)



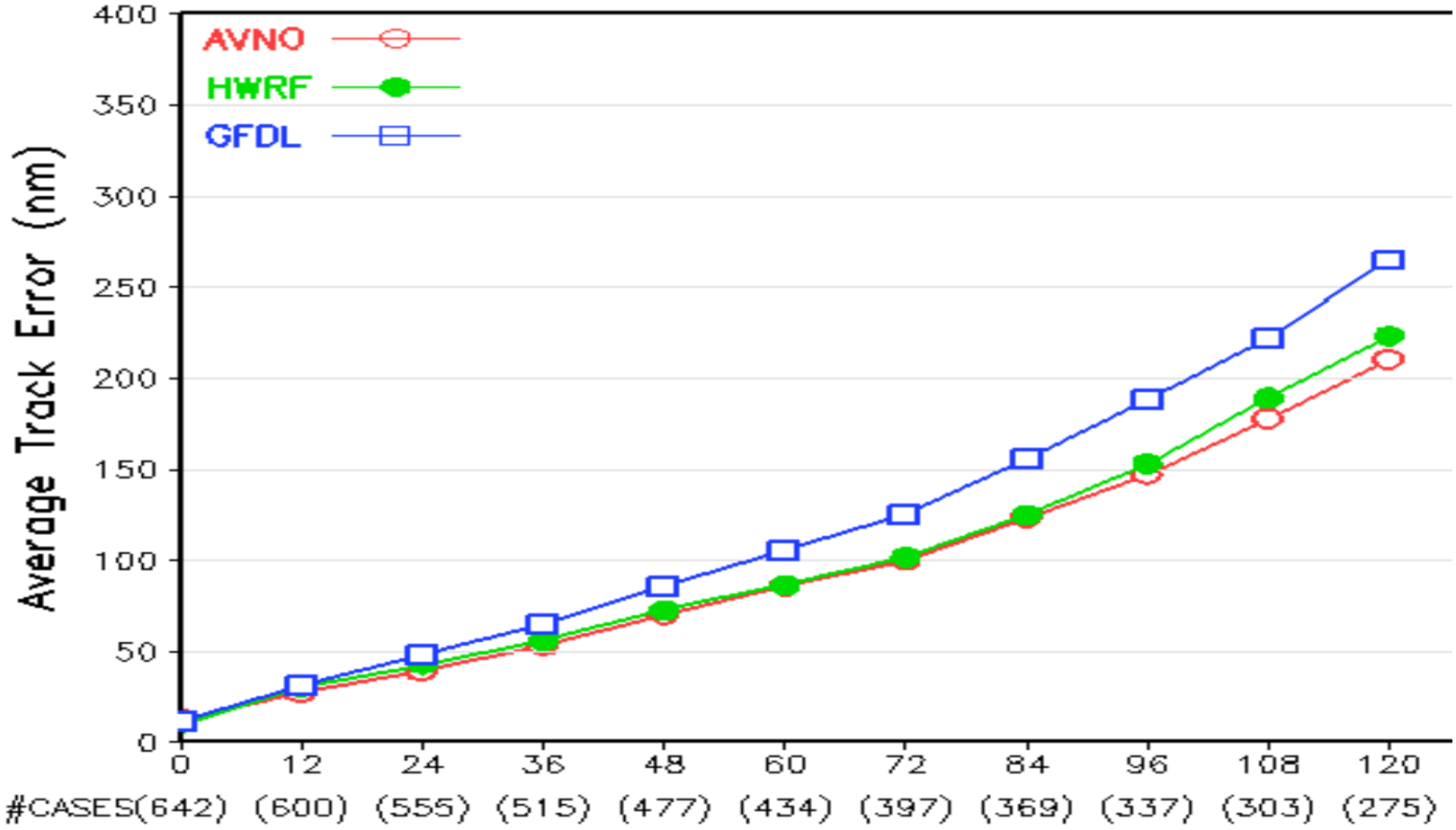

**GFS (AVNO) tied with UKM; ECMWF had the best skill.**

# 2015 Eastern Pacific – Track Errors (00Z and 12Z Cycles)




**GFS (AVNO), HWRF and ECMWF had similar skills.**

# 2015 Wesatern Pacific – Track Errors (00Z and 12Z Cycles)




**GFS (AVNO) and HWRF had similar skills.**

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# Implementation Overview

1) **The GDAS/GFS is being upgraded to 4D-Hybrid En-VAR System**
   - ***Research supported by Sandy Supplemental transitioning to operations***

2) **Land surface improvements to address summertime warm/dry biases in surface fields**

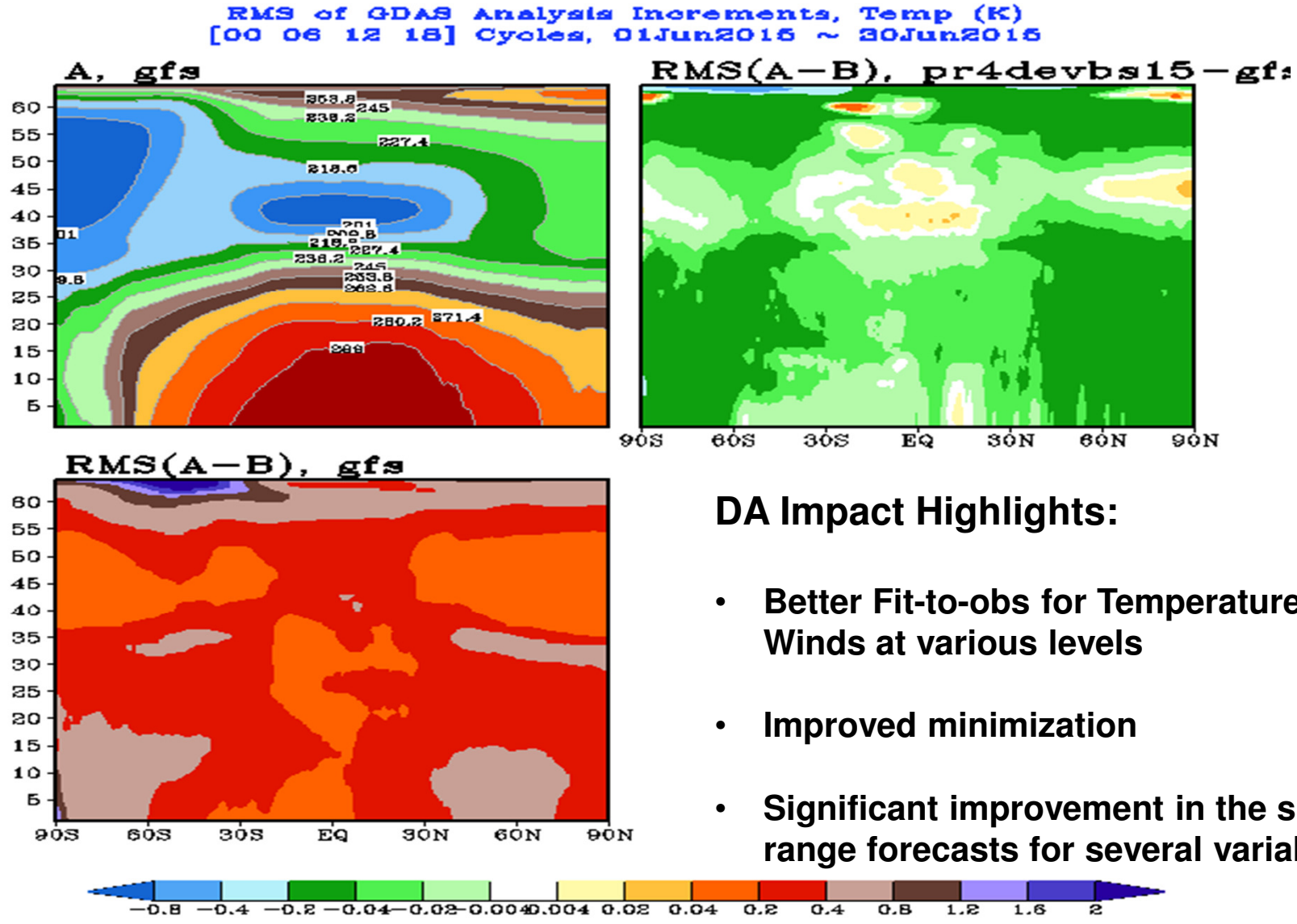
3) **Hourly output fields through 120-hr forecasts**

4) **36 months of retrospective runs for evaluation**

# Data Assimilation Upgrades

- Use 4D covariances instead of 3D
- Multivariate Ozone update
- Assimilate all-sky (clear and cloudy) radiances
- Bias correct aircraft data
- And other upgrades (e.g. CRTM, Data selection/thinning, AMV winds, etc.)

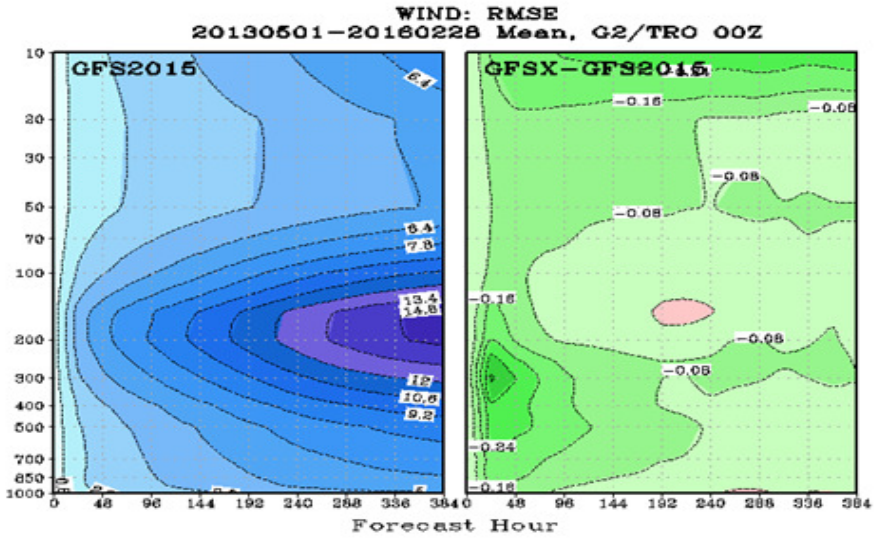
# GFSX much smaller increments
# Analysis and first guess in better agreement

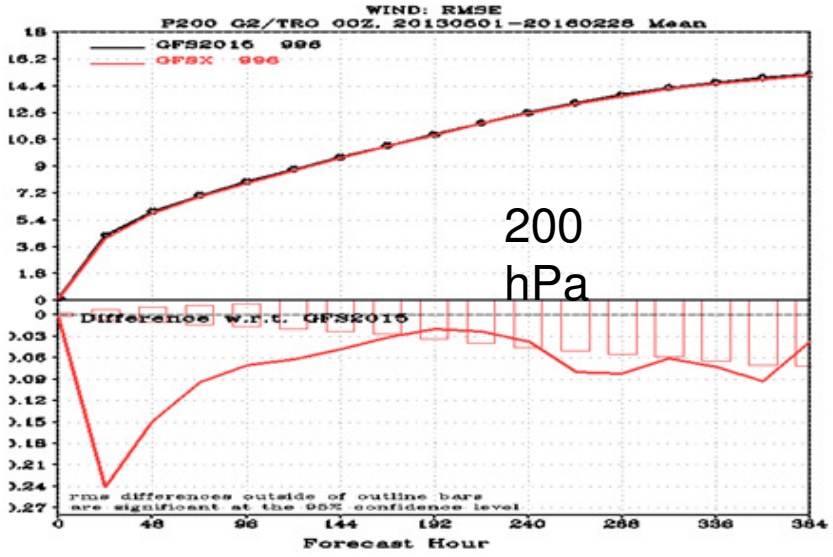



**DA Impact Highlights:**

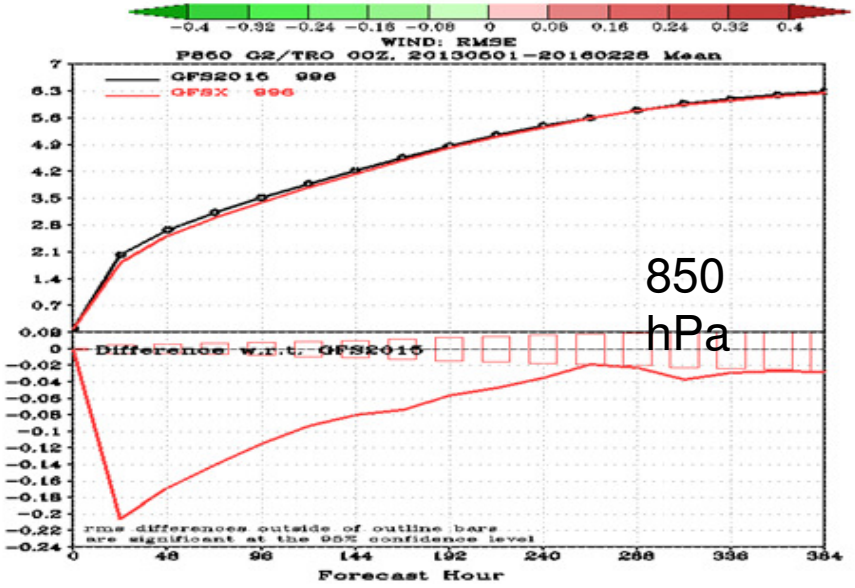
- **Better Fit-to-obs for Temperature and Winds at various levels**
- **Improved minimization**
- **Significant improvement in the short-range forecasts for several variables**

# RMSE for Winds: Global Tropics




200 hPa




850 hPa

Global Tropics
Winds RMSE

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   **verification extended from 5 days to 7 days**

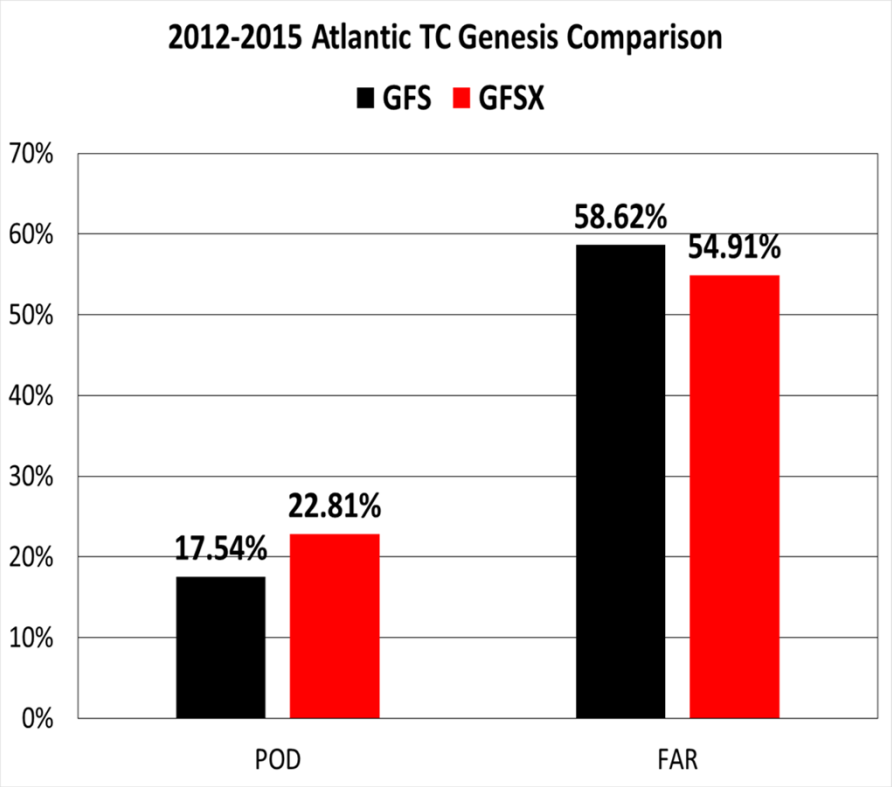
# Impact on Hurricanes: NHC Evaluation

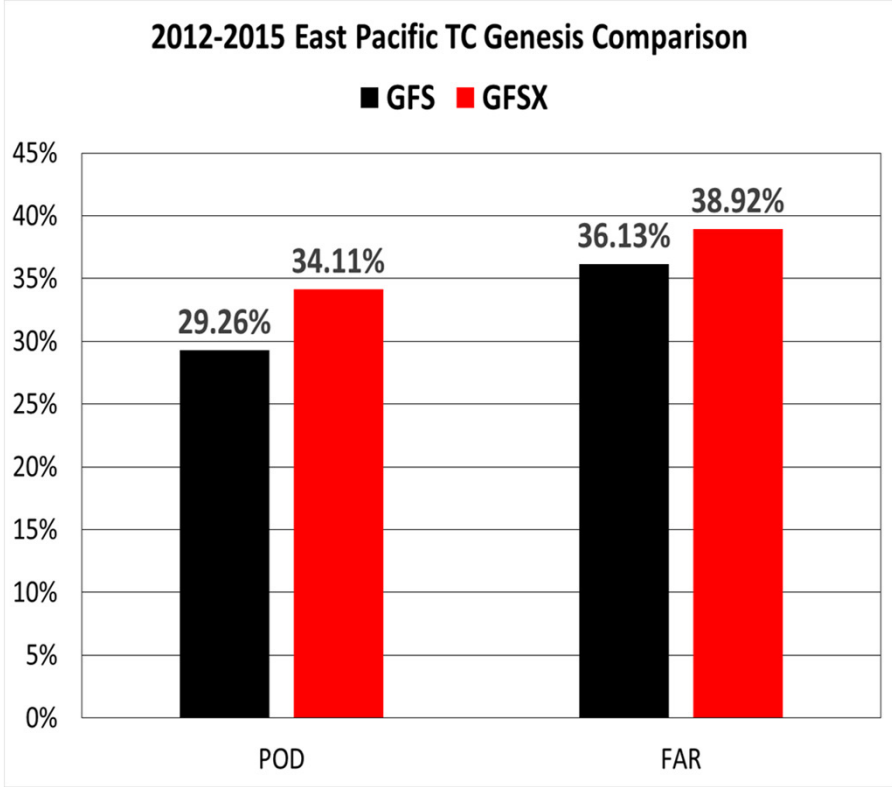
| AL | Track | Intensity |
|---|---|---|
| 0-48 h | - 3% | +5% |
| 72-120 h | +7% | + 11% |

| EP | Track | Intensity |
|---|---|---|
| 0-48 h | +5% | +5% |
| 72-120 h | +1% | +2% |

Track and intensity error improvements/degradation of Q3FY16 GFS vs. 2015 GFS for the 2012-2016 retrospective runs, by basin

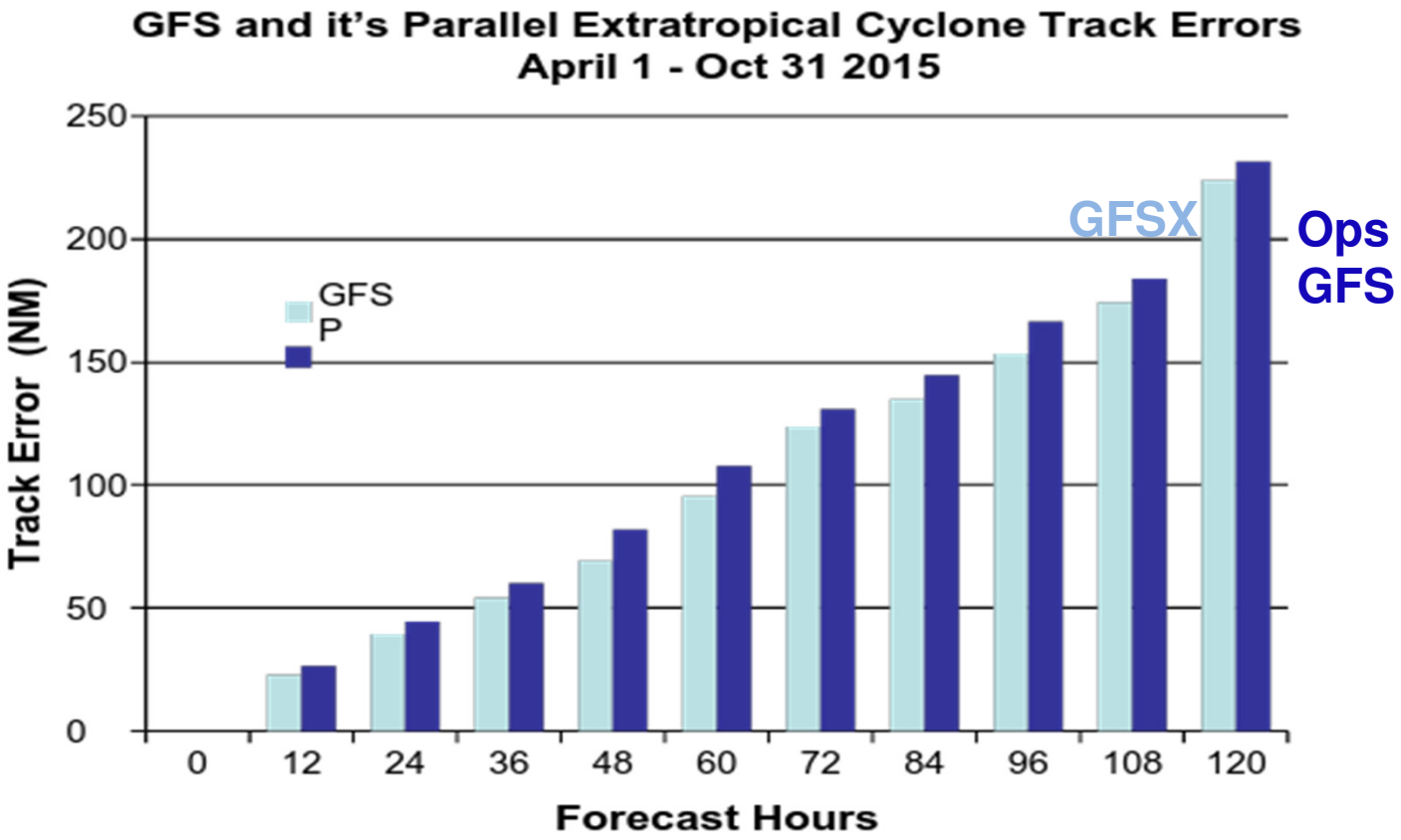
# Verification of TC cyclogenesis in the GFSX – comparison to current and previous version of the GFS (courtesy of Dan Halperin and Bob Hart)




**Increased POD, reduced False Alarm**

**Increased POD, increased False Alarm**



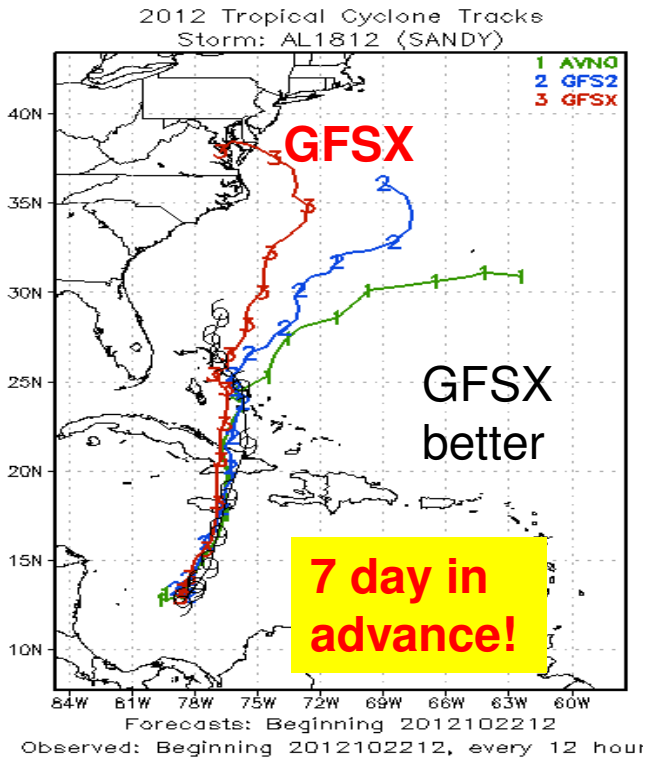

GFSO (blue) – Operational GFS (Control); GFSP (cyan) – Parallel GFS

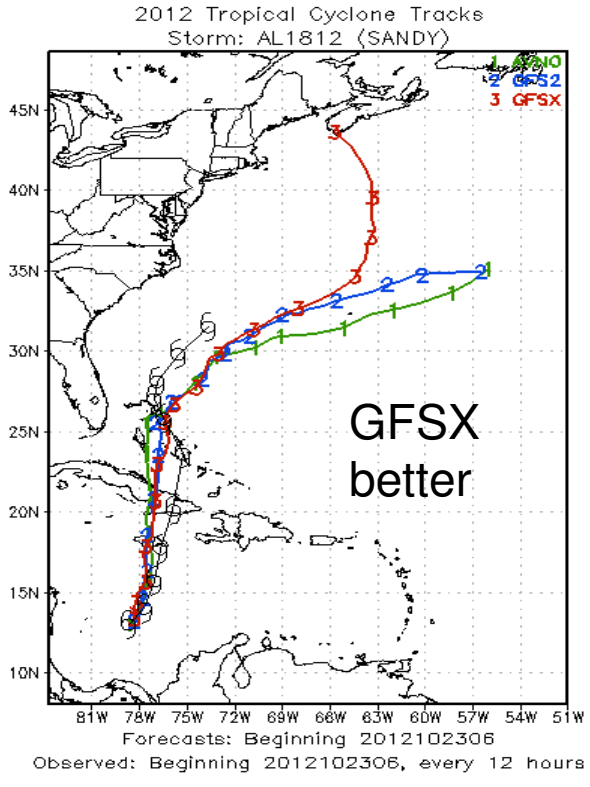
**Errors in GFSX are smaller than that in GFSO.**

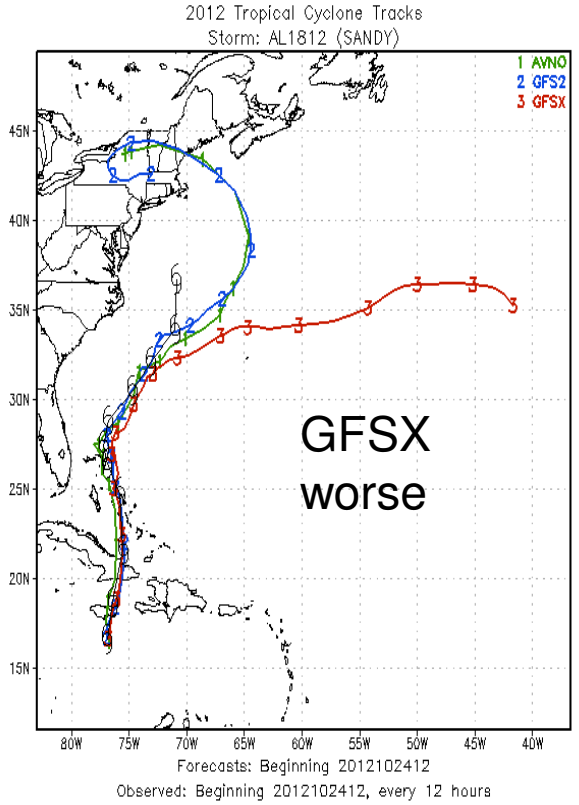
| Fcst hr | 0 | 12 | 24 | 36 | 48 | 60 | 72 | 84 | 96 | 108 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cases | 1093 | 1075 | 1011 | 687 | 366 | 201 | 104 | 64 | 35 | 26 | 17 |

Guang Ping Lou

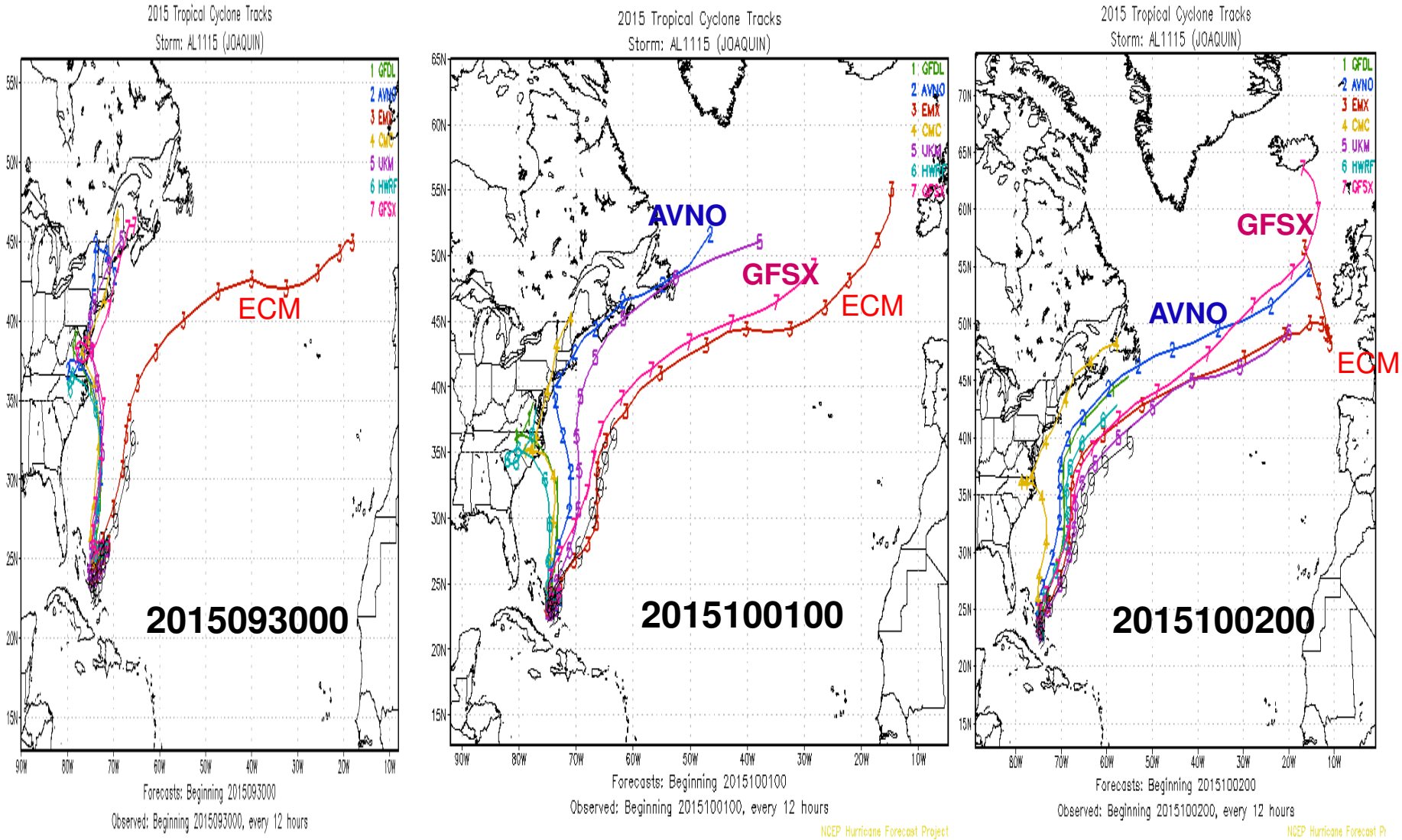
- **Hurricane Sandy:** Mean track indicates GFSX has much a better forecast than 2012 operational GFS and the current operational GFS2015 at the 7-day lead time.
- Overall, **GFSX's performance is similar to GFS2015**.
- One case (2012102412) showed GFSX is worse.



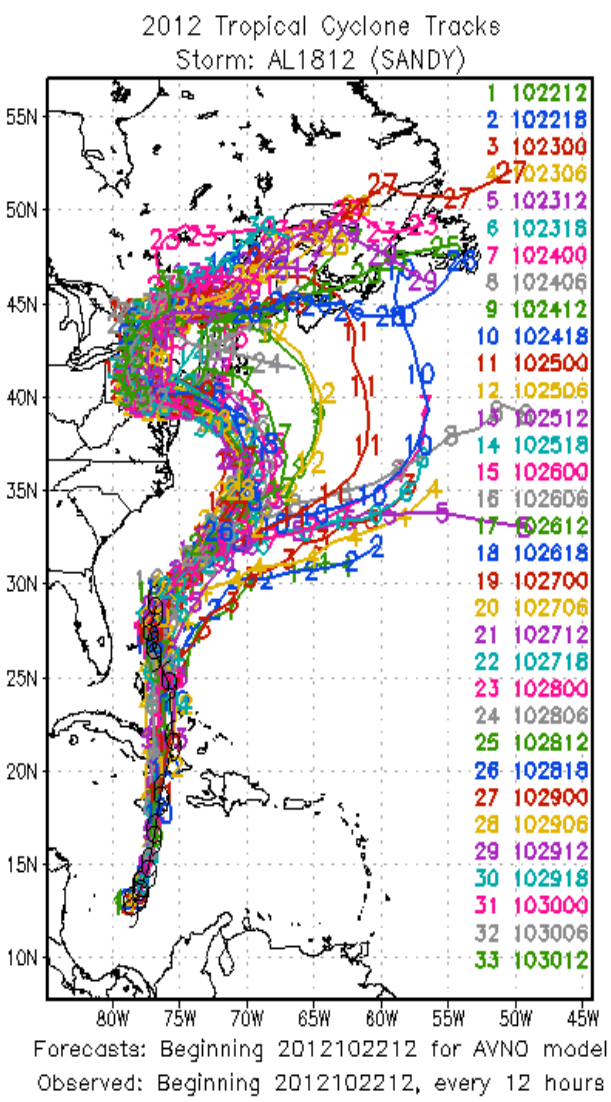



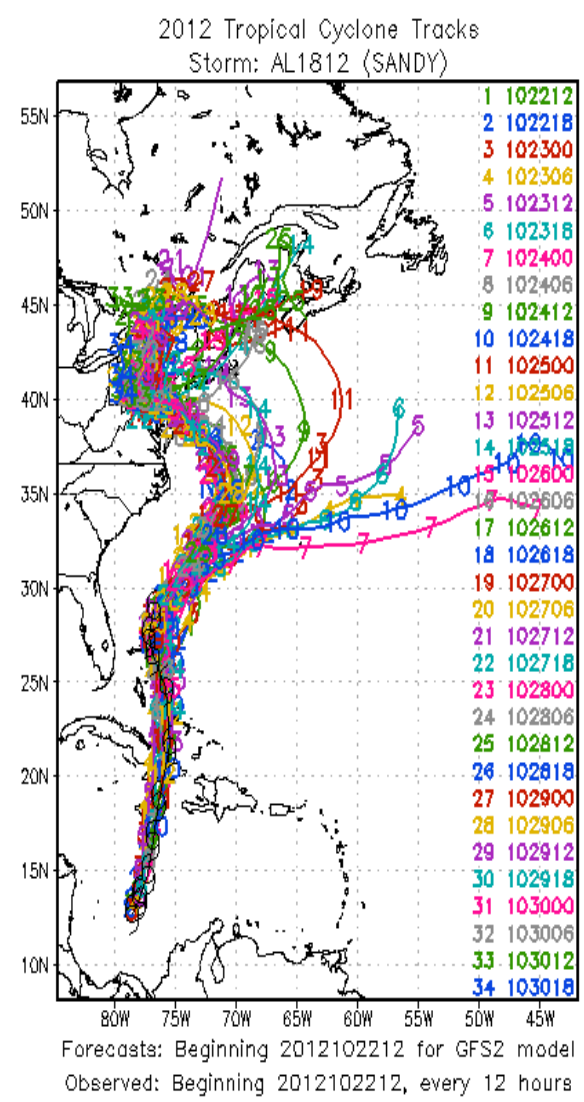
# Hurricane Joaquin

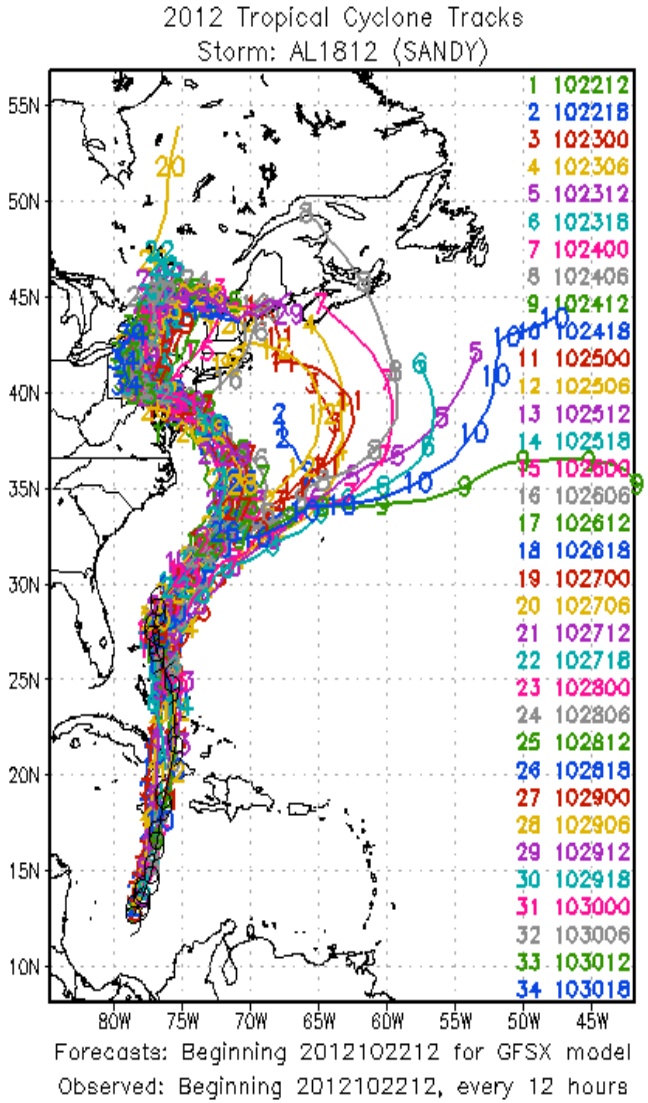



**GFSX performed much better than AVNO starting from the 2015100100 cycle**

# Extra slides



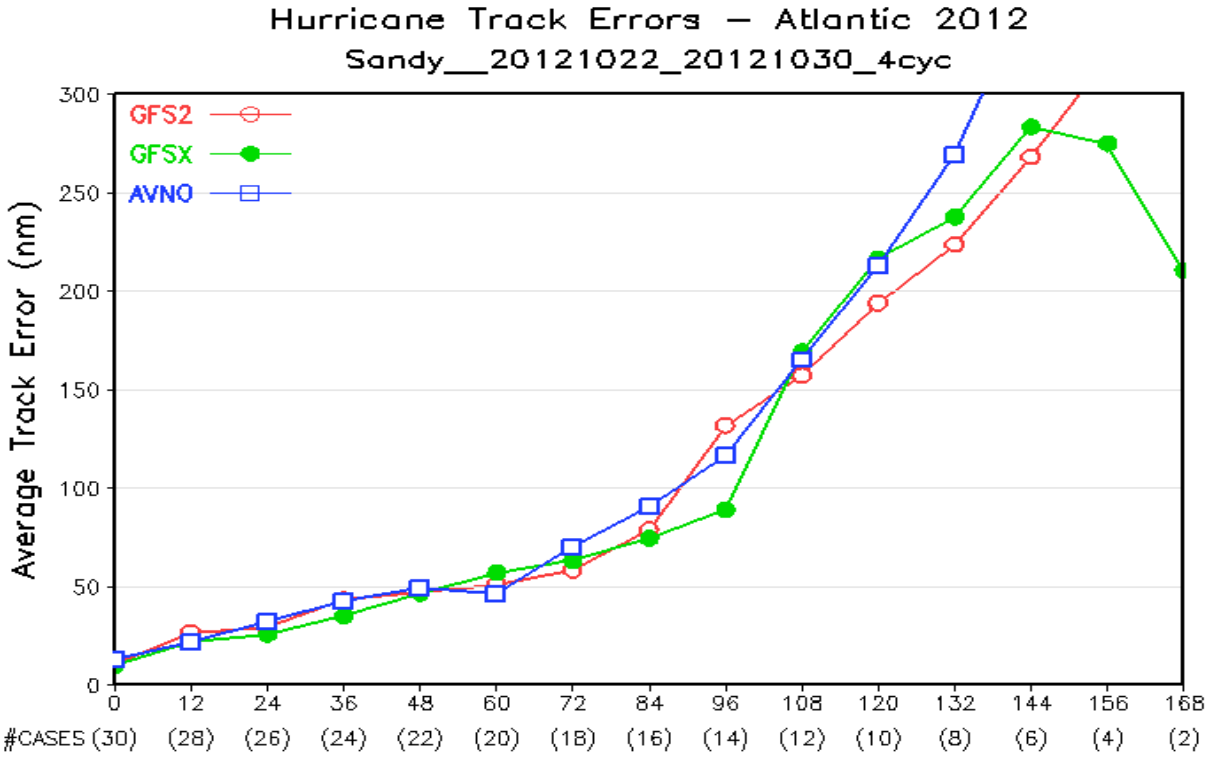




**2012 Operational GFS** **Current Operational SL-GFS** **GFSX**

- **GFSX has a couple of cases of early detection**
- **Overall, there are not much differences between the three models**

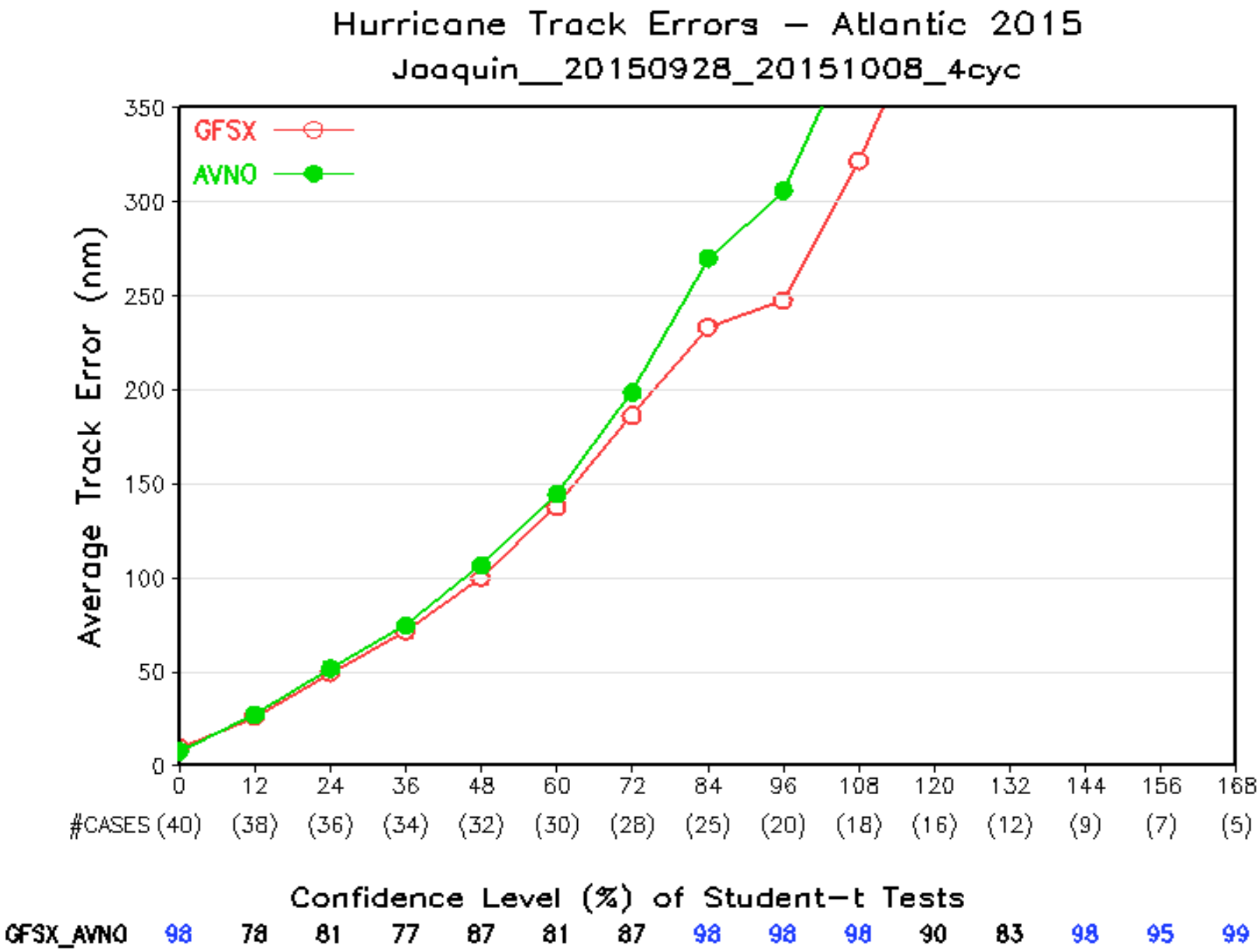
# Hurricane Sandy




Confidence Level (%) of Student−t Tests

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GFS2_GFSX | 82 | 95 | 89 | 97 | 53 | 84 | 72 | 66 | 97 | 70 | 80 | 83 | 78 | 90 | 99 |
| GFS2_AVNO | 84 | 94 | 74 | 53 | 67 | 72 | 81 | 80 | 91 | 64 | 76 | 84 | 99 | 99 | 99 |
| GFSX_AVNO | 96 | 50 | 90 | 90 | 65 | 91 | 70 | 88 | 88 | 58 | 55 | 86 | 99 | 99 | 99 |

GFS2: T1534 GFS implemented in January 2015 (3D En-Var)
GFSX: T1534 GFS to be implemented in May 2016 (4D En-Var)
AVNO: 2012 operational GFS (T574 Eulerian GFS, 3D En-Var, ~23km)


Hurricane Track Errors — Atlantic 2015
Joaquin__20150928_20151008_4cyc
GFSX
AVNO
Average Track Error (nm)
350
300
250
200
150
100
50
0
0 12 24 36 48 60 72 84 96 108 120 132 144 156 168
#CASES (40) (38) (36) (34) (32) (30) (28) (25) (20) (18) (16) (12) (9) (7) (5)
Confidence Level (%) of Student-t Tests
GFSX_AVNO 98 78 81 77 87 81 87 98 98 98 90 83 98 95 99

**Credit: Tracey Dorian**

The European Center Model (ECMWF) fairly quickly figured out that the storm would not make landfall, while NCEP's Global Forecast System (GFS) was slower to capture the decreasing threat. …

The GFS parallel … was very slightly better than the operational GFS. …The 00z 1 October cycle (Fig. 6) still saw the GFS and GFS turn Joaquin too far to the west after the initial southwest motion. …

The GFS simulation of Joaquin was therefore possibly influenced by the large upper low over the southeast, and the model still made a landfall, although dramatically further north than previous cycles.

**The GFSX, however, did not show landfall, although its track was still too far to the west. .. The GFSX parallel was 6 hours faster than the operational GFS in dismissing the east coast threat**.

| | |
|---|---|
| **ECMWF** | 00Z Sep 29 |
| **GFSX** | 00Z Oct 1 |
| **UKMET** | 00Z Oct 1 |
| **GFS** | 06Z Oct 1 |
| HWRF | 12Z Oct 1 |

Table 1. Lists of the first cycles for which various forecast models first indicated that Joaquin would not make landfall along the east coast and kept the storm offshore in all subsequent cycles

# Forecast Model and Product Changes

- Convective gravity wave upgrade
- Tracer adjustment upgrade
- ***Corrections to land surface to reduce summertime warm, dry bias over Great Plains***

  GFS showed too little evaporation and too much sensible heat flux, hence Bowen ratio is too high. Upgraded LSM includes

  - **rsmin for grassland from 45 to 20**
  - **rsmin for cropland from 45 to 20**
  - **roughness length for cropland from 3.5cm to 12.5cm (used to address too strong surface winds)**
- Improved icing probability products and new icing severity product
- ***5 more levels above 10 hPa***
- ***Hourly output through 120-hr forecast***



**Credit: Slide from GFS Implementation Review**

# Retrospective Forecast Experiments
# 36 months from 2012 to 2016

**GCWMB real time (pr4devb):** period: 2015070100 - real time

**GCWMB 2015 summer retrospective (pr4devbs15)**
period: 2015041500 - 2015120100 (230 days)

**GCWMB 2013 summer retrospective (pr4devbs13)**
period: 2013041500 - 2013120100 (230 days)

**NCO 2013-2014 winter retrospective (pr4devbw13)**
period: 2013110100 - 2014060100 (212 days)

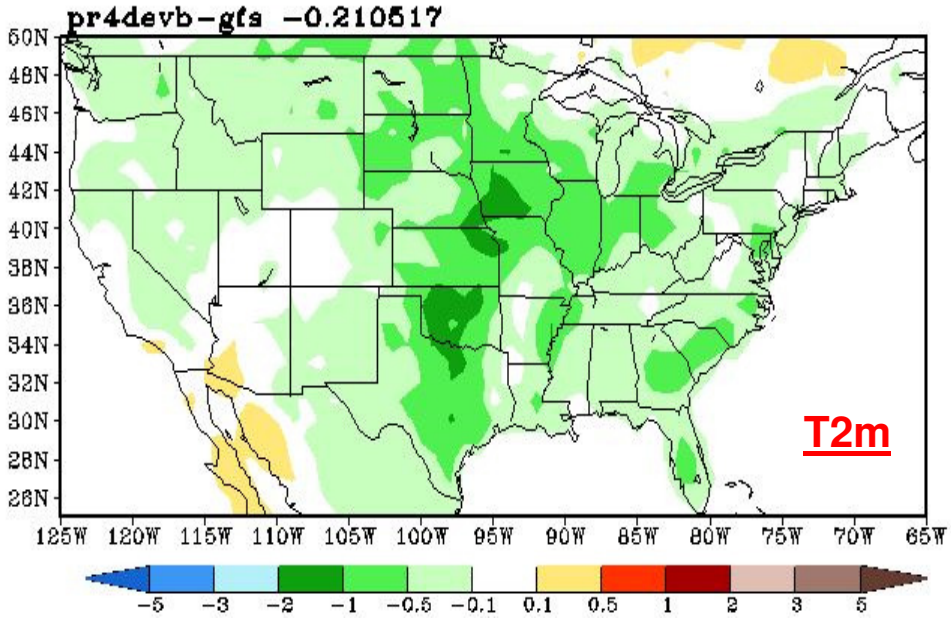
**NCO 2014 summer retrospective (pr4devbs14)**
period: 2014050100 - 2014120100 (214 days)

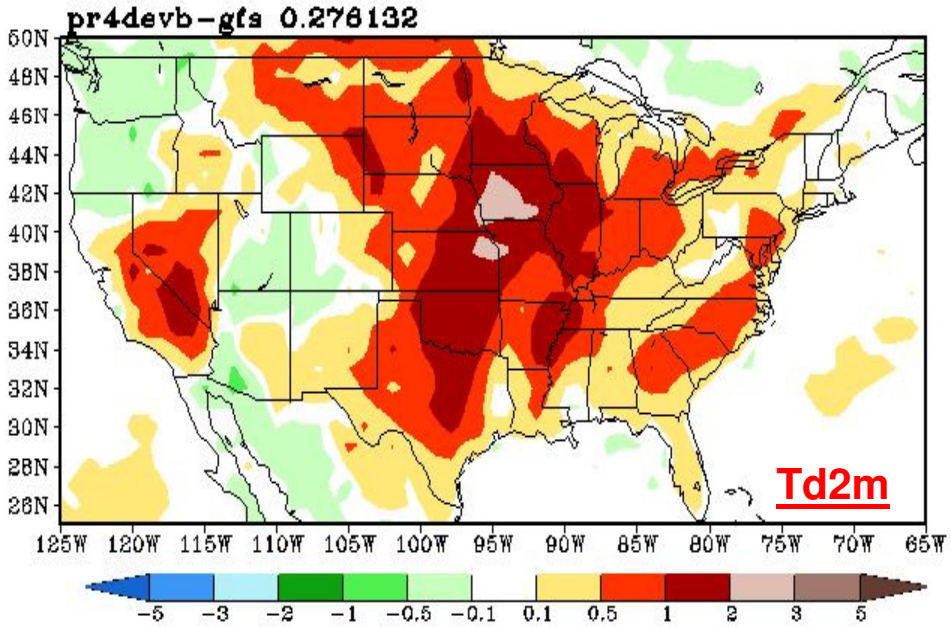
**GCWMB 2014-2015 winter retrospective (pr4devbw14**)
period: 2014110100 - 2015070100 (242 days)

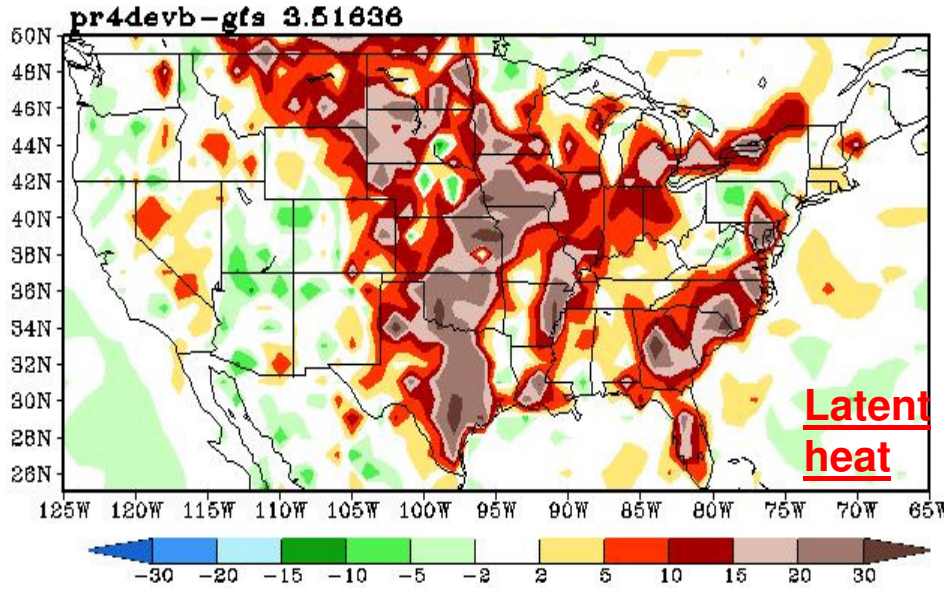
**GCWMB Special retrospective for Hurricane Sandy**
period: 2012101700 - 201213100 (15 days)

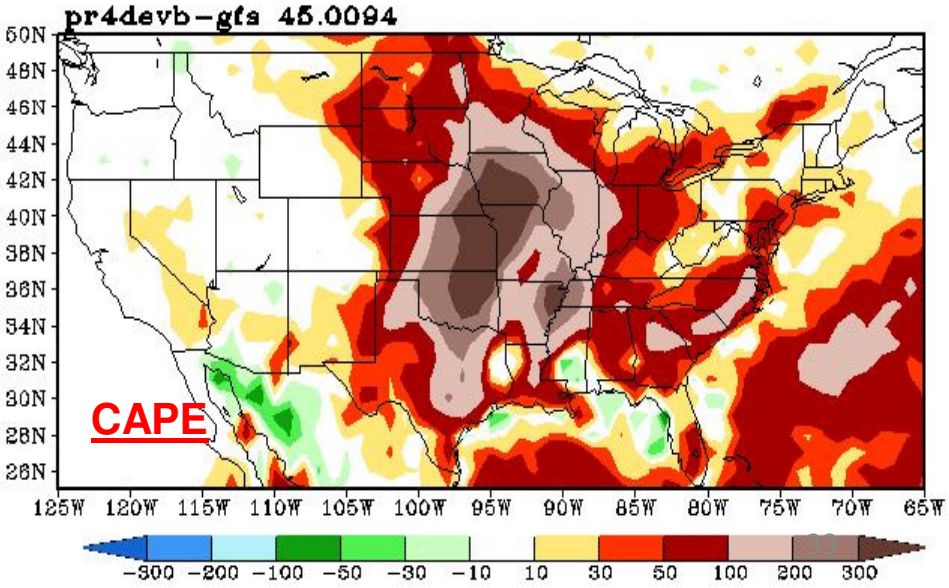
# Significantly improve the biases brought up in the EMC MEG meeting

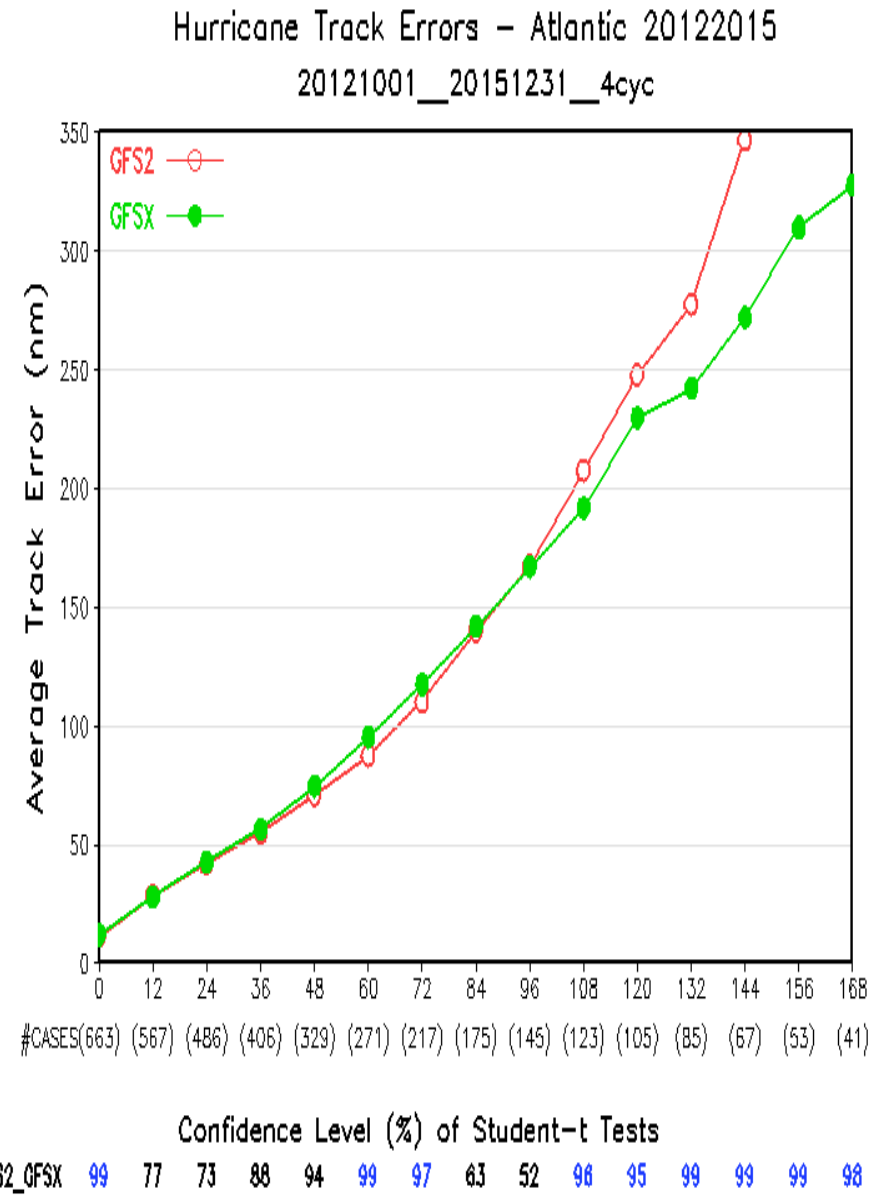
EMC land surface team

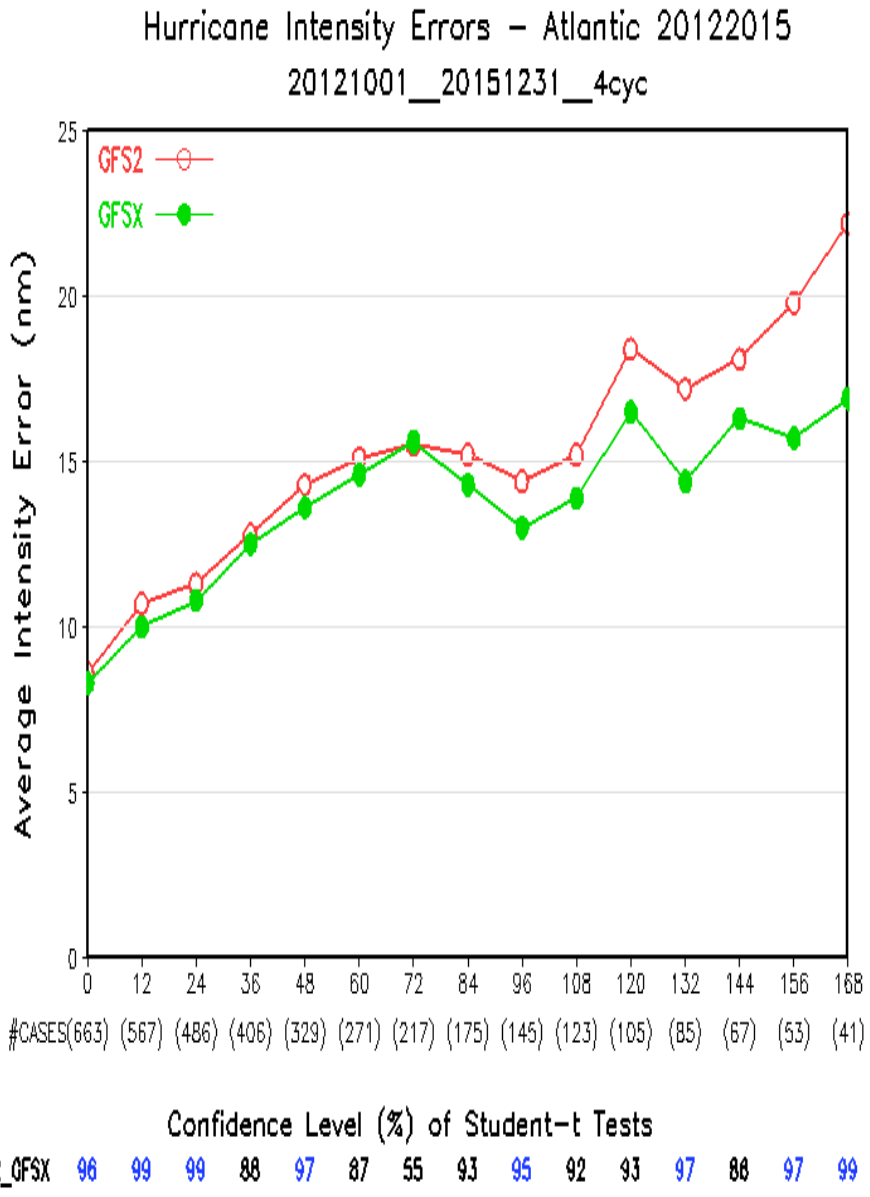


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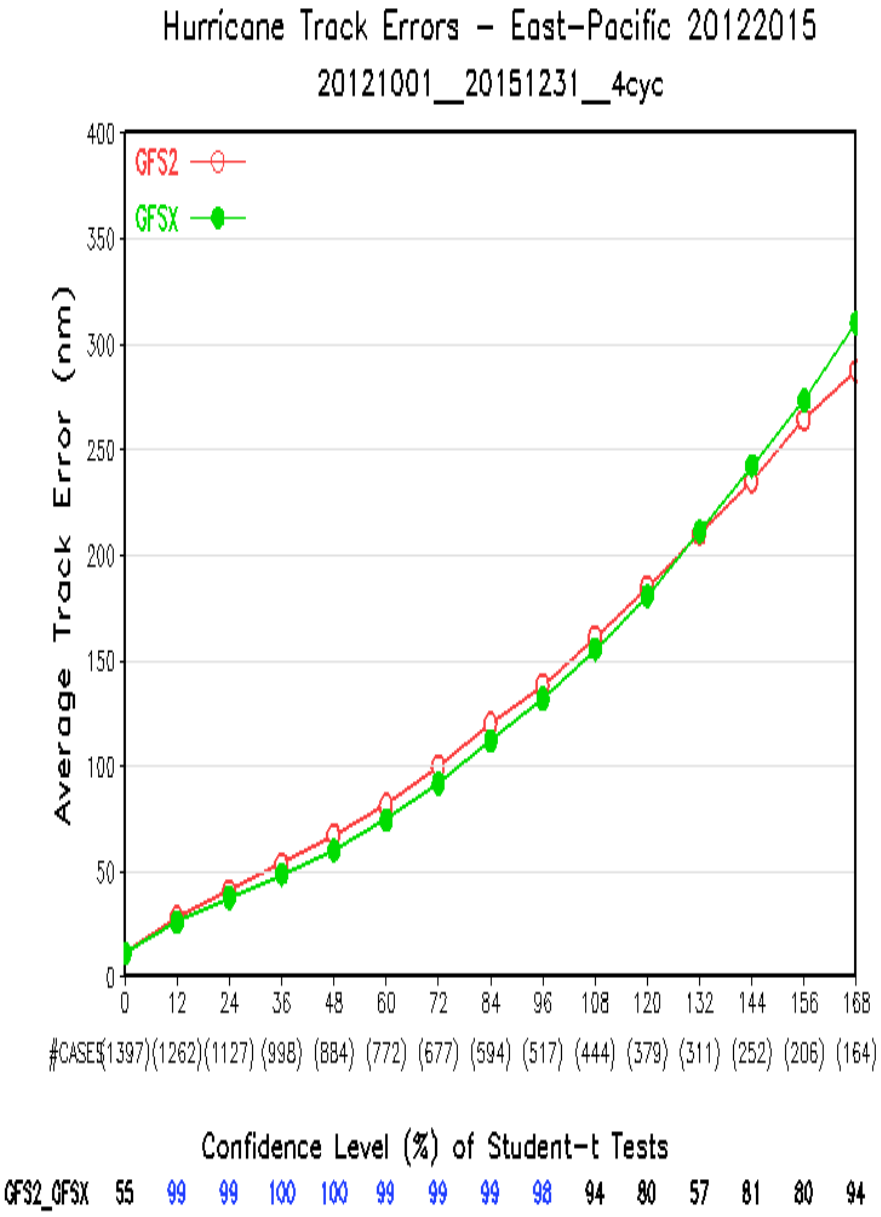
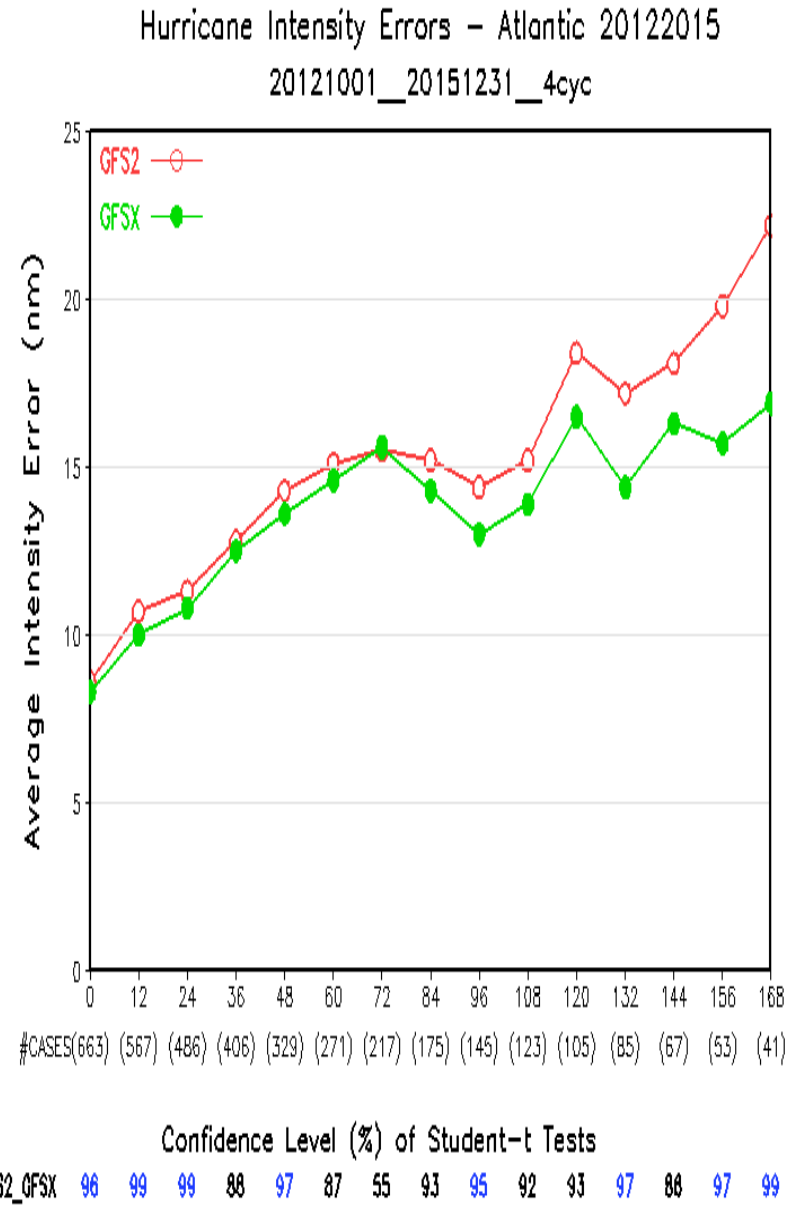
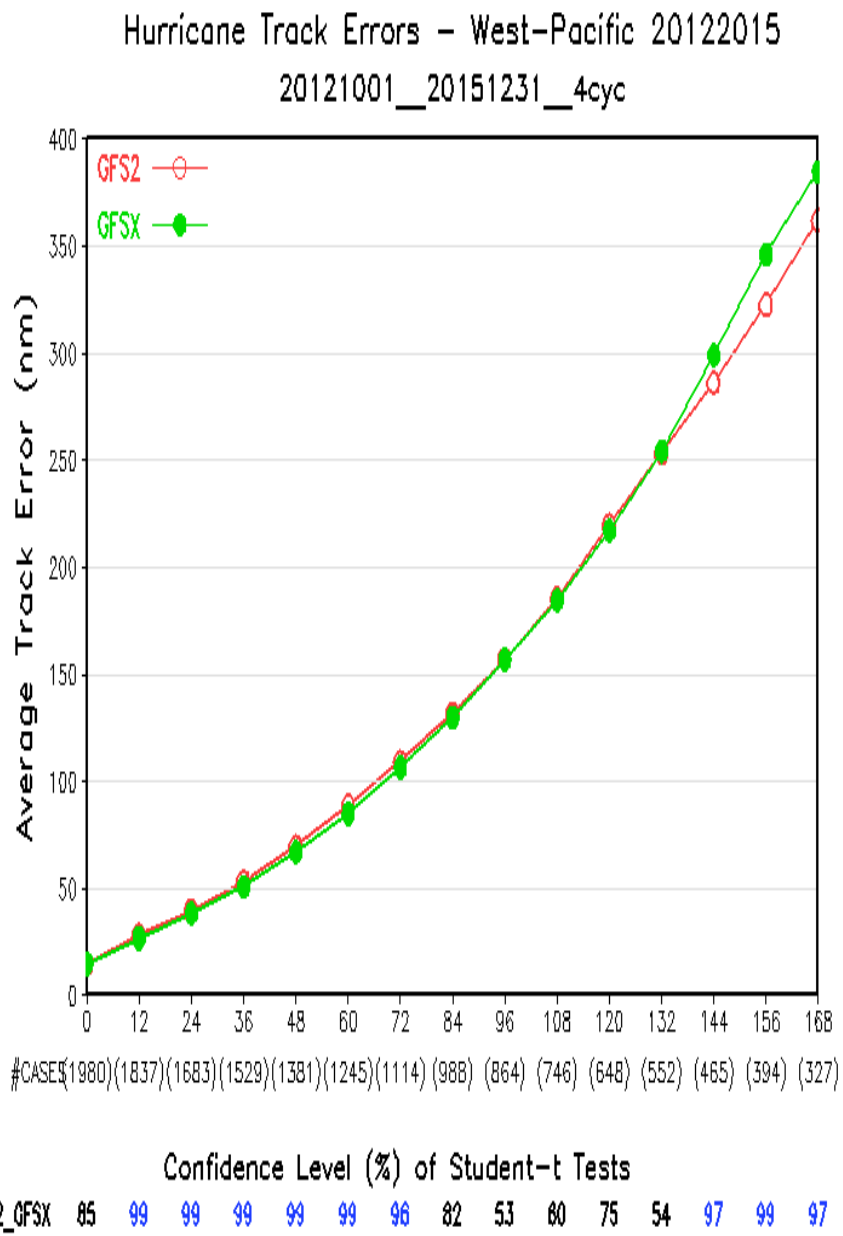
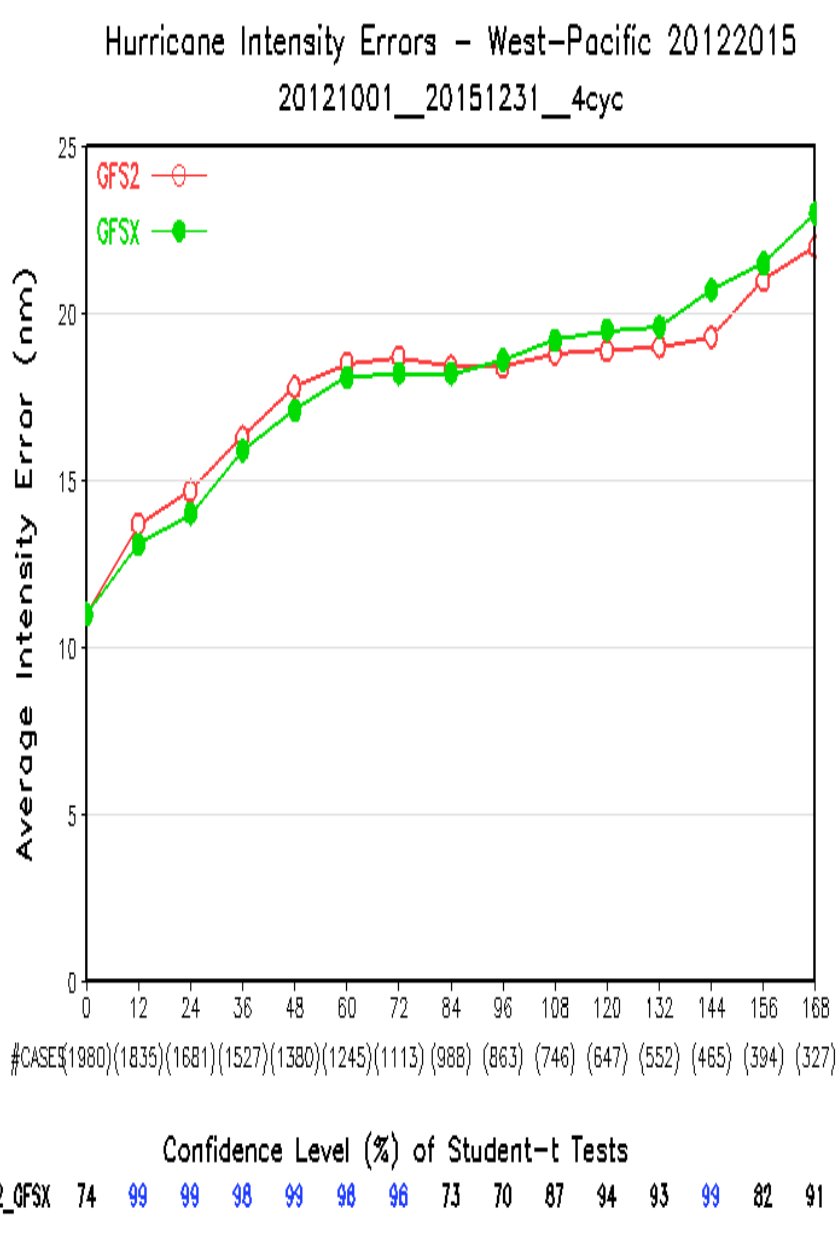
GFSX: T1534 GFS to be implemented in May 2016 (4D En-Var)


Hurricane Track Errors - East-Pacific 20122015
20121001_20151231_4cyc
GFS2
GFSX
Average Track Error (nm)
0
50
100
150
200
250
300
350
400
0 12 24 36 48 60 72 84 96 108 120 132 144 156 168
#CASES (1397) (1262) (1127) (998) (884) (772) (677) (594) (517) (444) (379) (311) (252) (206) (164)
Confidence Level (%) of Student-t Tests
GFS2_GFSX 55 99 99 100 100 99 99 99 98 94 80 57 81 80 94


Hurricane Intensity Errors - Atlantic 20122015
20121001_20151231_4cyc
GFS2
GFSX
Average Intensity Error (nm)
0
5
10
15
20
25
0 12 24 36 48 60 72 84 96 108 120 132 144 156 168
#CASES (663) (567) (486) (406) (329) (271) (217) (175) (145) (123) (105) (85) (67) (53) (41)
Confidence Level (%) of Student-t Tests
GFS2_GFSX 96 99 99 88 97 87 55 93 95 92 93 97 88 97 99


Hurricane Track Errors - West-Pacific 20122015
20121001_20151231_4cyc
GFS2
GFSX
Average Track Error (nm)
0
50
100
150
200
250
300
350
400
0 12 24 36 48 60 72 84 96 108 120 132 144 156 168
#CASES (1980) (1837) (1683) (1529) (1381) (1245) (1114) (988) (864) (746) (648) (552) (465) (394) (327)
Confidence Level (%) of Student-t Tests
GFS2_GFSX 85 99 99 99 99 99 96 82 53 60 75 54 97 99 97


Hurricane Intensity Errors - West-Pacific 20122015
20121001_20151231_4cyc
GFS2
GFSX
Average Intensity Error (nm)
0
5
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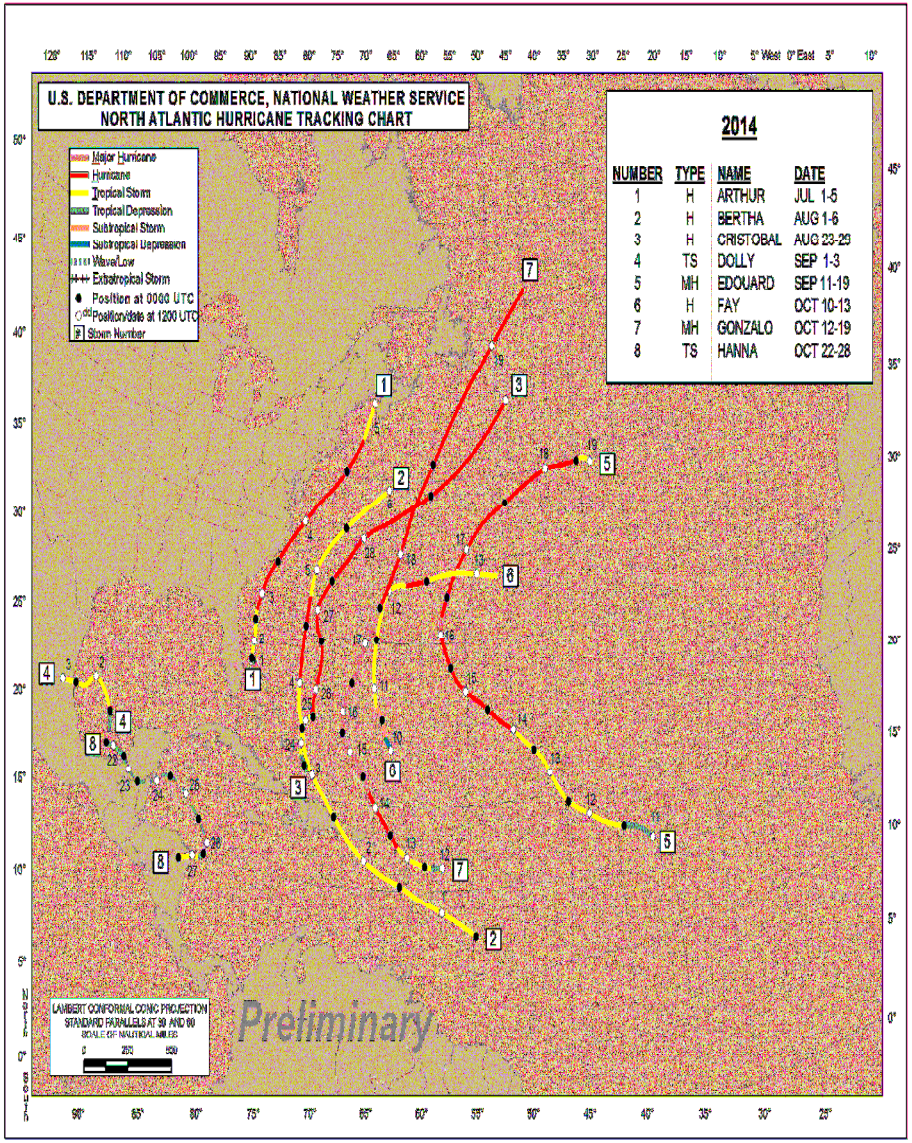
0 12 24 36 48 60 72 84 96 108 120 132 144 156 168
#CASES (1980) (1835) (1681) (1527) (1380) (1245) (1113) (988) (863) (746) (647) (552) (465) (394) (327)
Confidence Level (%) of Student-t Tests
GFS2_GFSX 74 99 99 98 99 96 96 73 70 87 94 93 99 82 91

# 2014 Atlantic Hurricanes



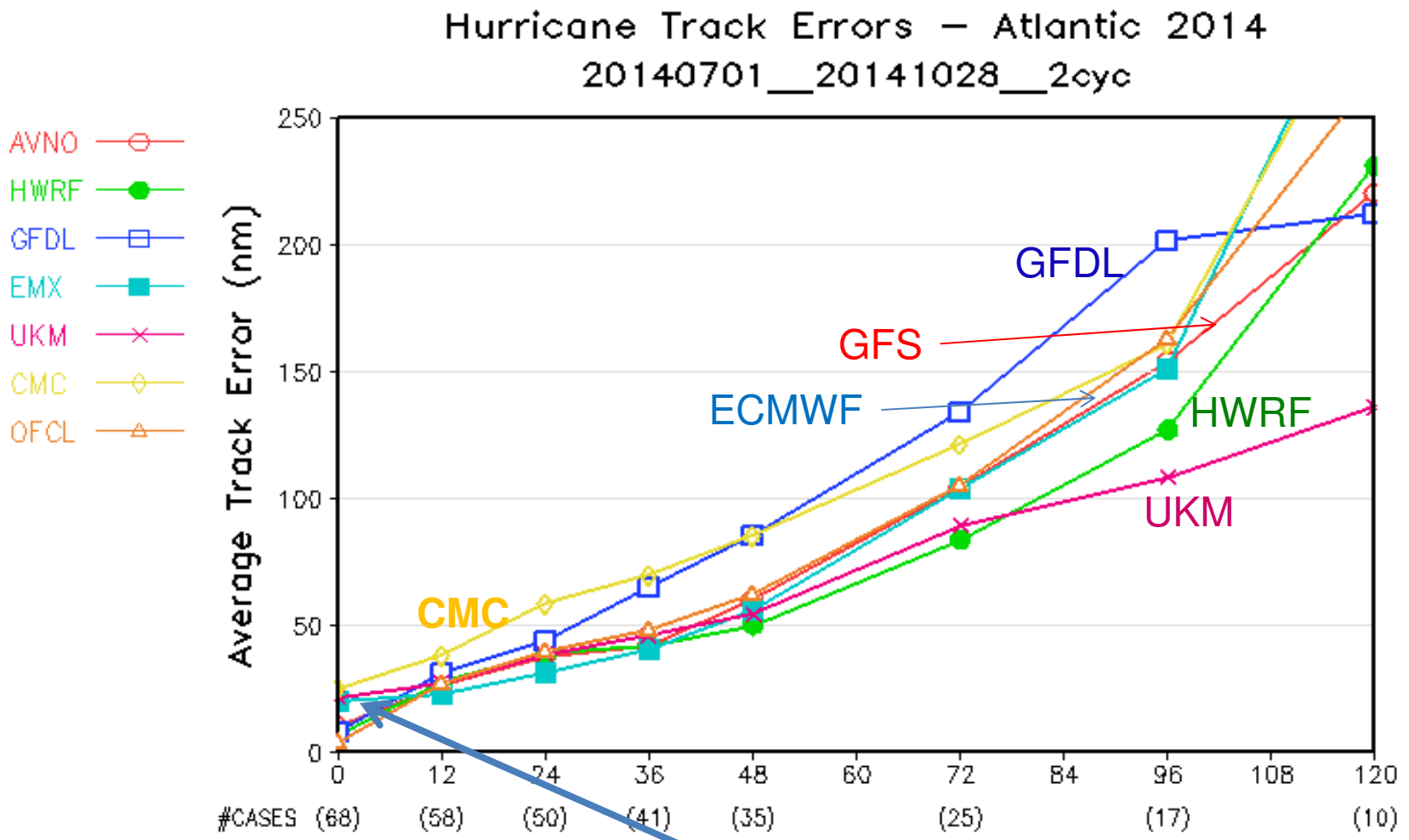

www.nhc.noaa.gov

| | |
|---|---|
| First system formed | July 1, 2014 |
| Last system dissipated | October 28, 2014 |
| Strongest storm | Gonzalo – 940 hPa , 145 mph |
| Total depressions | 9 |
| Total storms | 8 |
| Hurricanes | 6 |
| Major hurricanes (Cat. 3+) | 2 |
| Total fatalities | 19 total |
| Total damage | ~ $262 million |

http://www.wikipedia.org

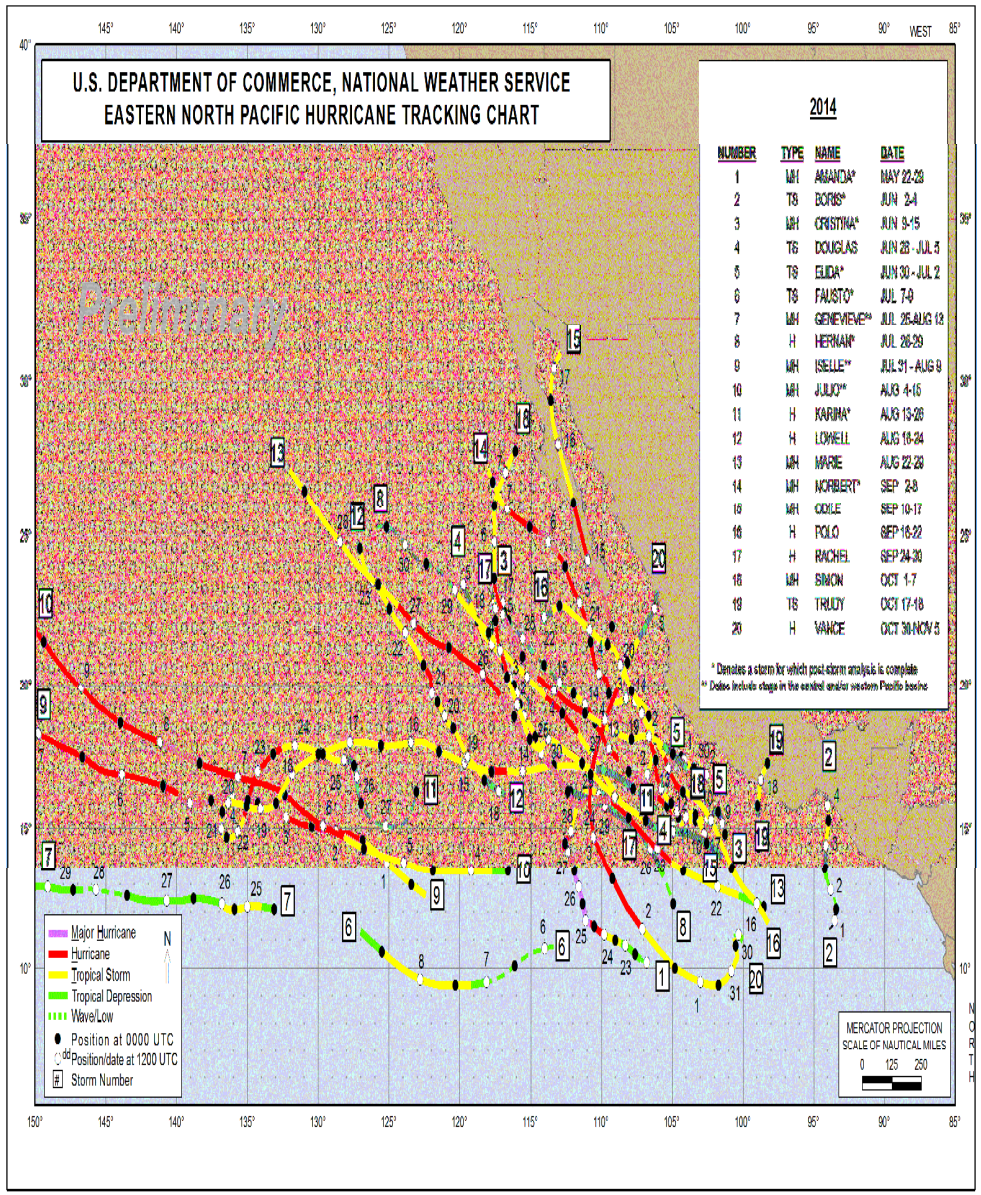
A quiet year. One landfall storm over US

**NOAA's Atlantic Hurricane Season Outlook (08/07/2014): 7-12 named storms, 3-6 hurricanes, 0-2 major hurricanes**



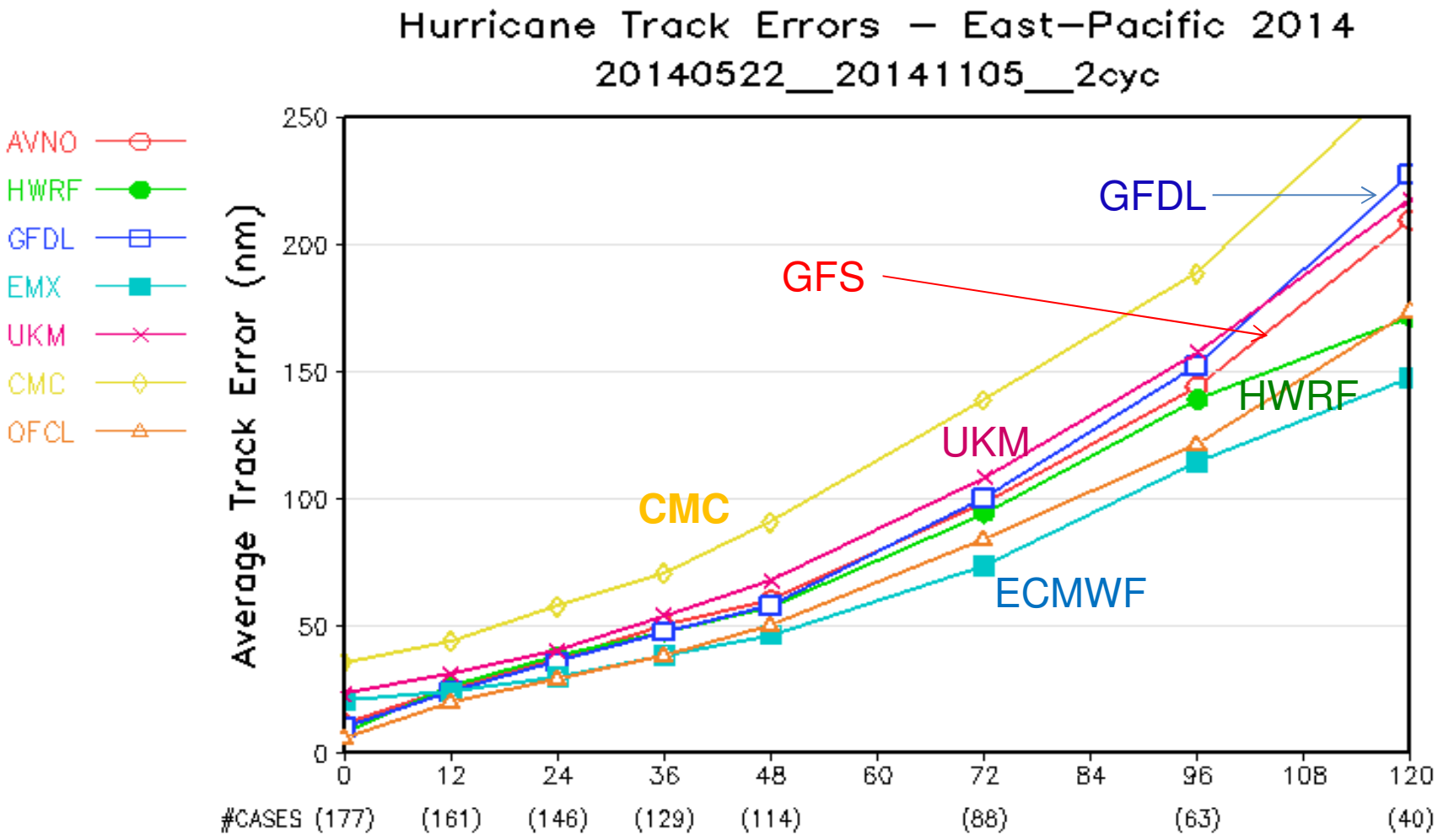

- **HWRF and UKM had better track forecasts. ECMWF had smaller errors than GFS for day1-2 forecasts, and larger error for day-5 forecast.**
- **Among all global NWP models, GFS had the smallest initial track error (because of the use of hurricane relocation ?)**
- **Note: OFCL are based on guidance of "early" models**

# 2014 Eastern Pacific Hurricanes



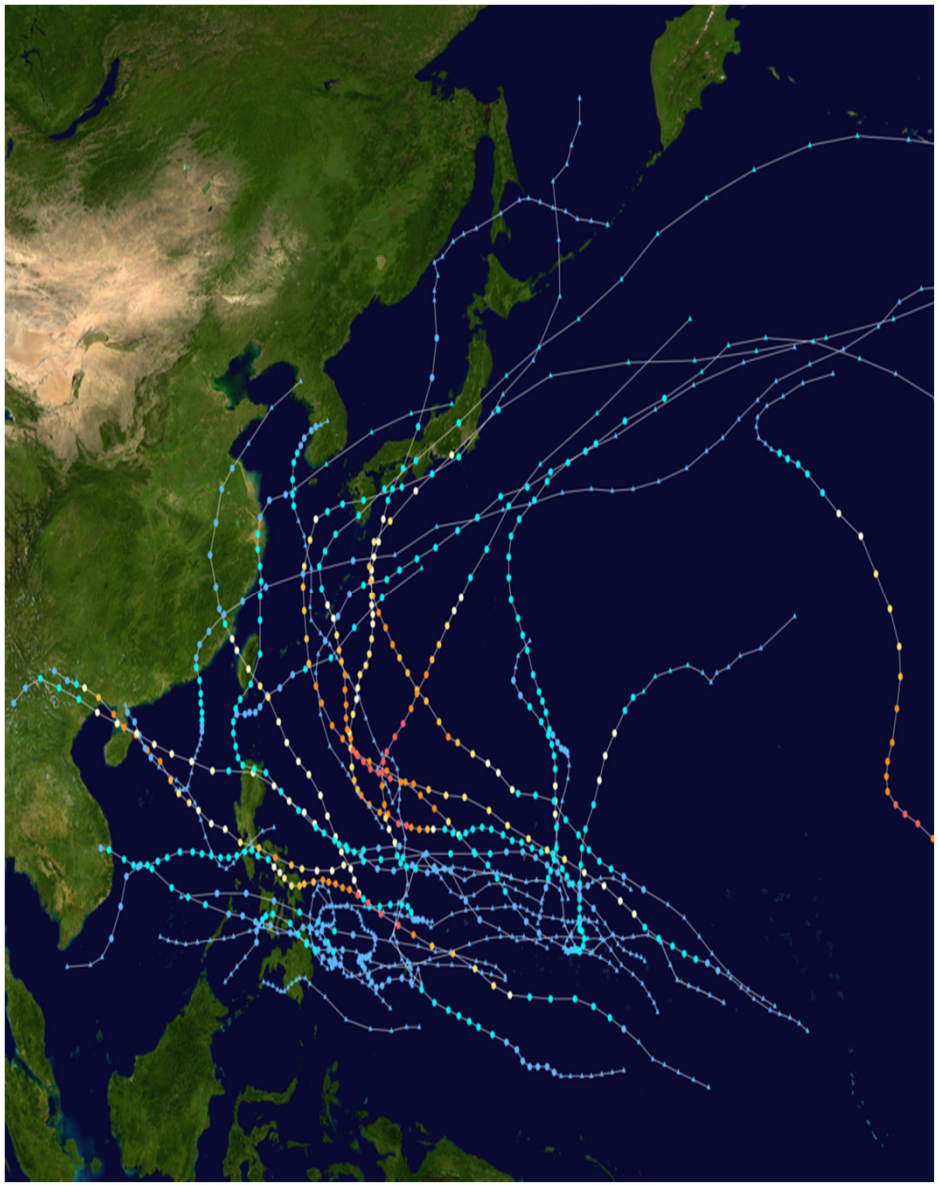

www.nnc.noaa.gov/

| | |
|---|---|
| First system formed | May 22, 2014 |
| Last system dissipated | November 5, 2014 |
| Strongest storm | Marie – 918 hPa, 160 mph |
| Total depressions | 23 |
| Total storms | 22 |
| Hurricanes | 16 (record high, tied with 1990 and 1992) |
| Major hurricanes (Cat. 3+) | 9 |
| Total fatalities | 42 |
| Total damage | $1.24 billion |



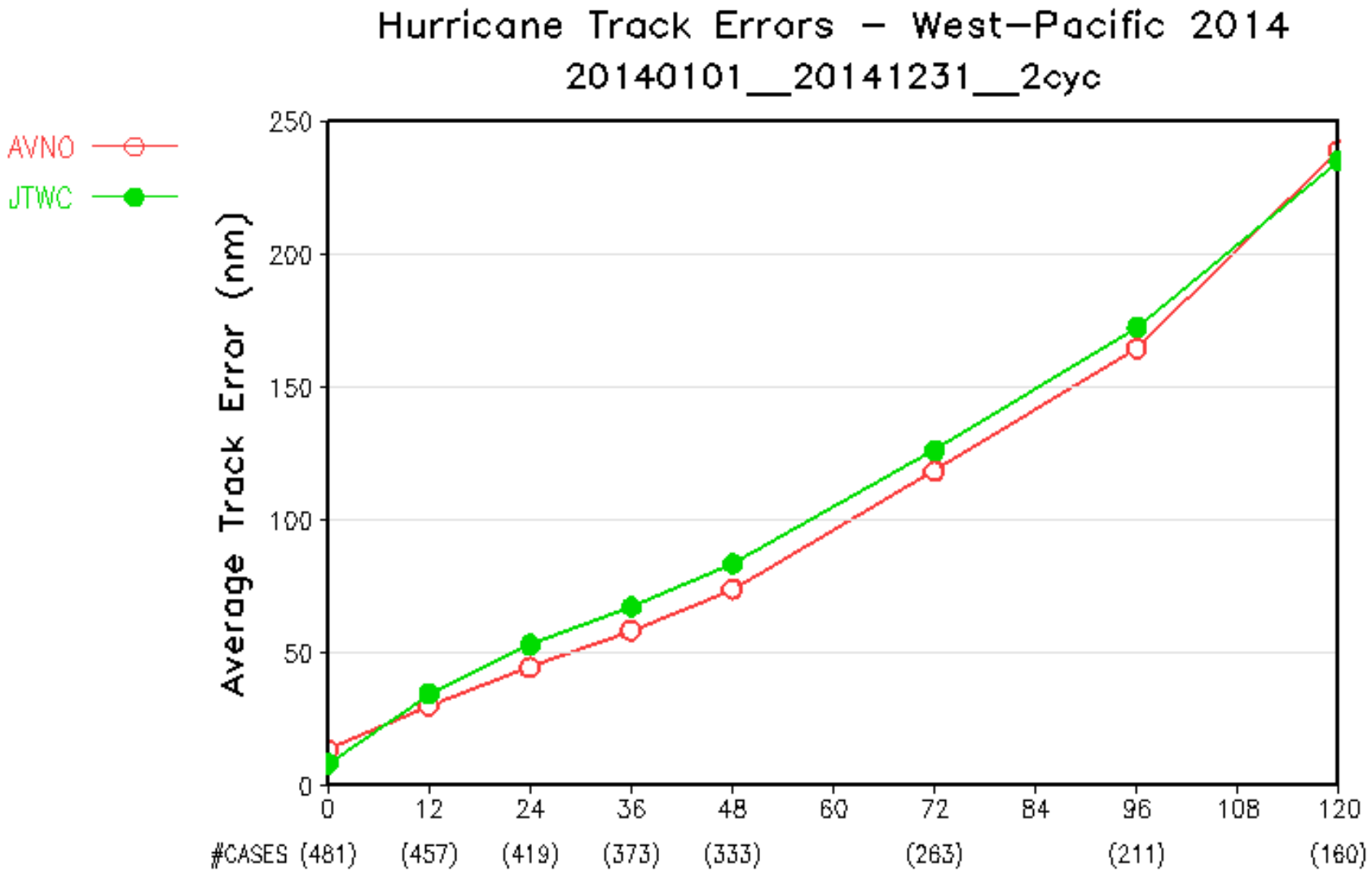

- **ECMWF had the smallest track errors.**
- **GFS was slightly worse than HWRF, but better than GFDL and UKM.**
- **CMC had the largest track error.**

# 2014 Western Pacific Typhoons



| | |
|---|---|
| First system formed | January 10, 2014 |
| Last system dissipated | January 1, 2015 |
| Strongest storm | Vongfong: 900 hPa, 130 mph |
| Total depressions | 30 |
| Total storms | 23 |
| Typhoons | 11 |
| Supper Typhoons | 8 |
| Total fatalities | 538 |
| Total damage | $8.4 billion |

http://www.wikipedia.org




JTWC are based on guidance of early models